The TREND IN ENGINEERING

at the University of Washington

In this issue:

PHOTOGRAMMETRY OF GLACIERS

A DEVICE FOR MEASURING THE SWELL PRESSURE OF SOIL

DIELECTRIC LOADING OF WAVEGUIDES

PROCESS DESIGN OF FIXED-BED CATION-EXCHANGE UNITS

PUBLICATIONS AND THESES COLLEGE OF ENGINEERING 1956 - 1957

July, 1957

Published quarterly

by

THE ENGINEERING EXPERIMENT STATION

THE GRADUATE MEETS INDUSTRY

THE UNIVERSITY OF WASHINGTON awarded bachelor's degrees in engineering to 467 graduates last month, compared with 329 in June, 1956. Early records available of about 160 who have accepted jobs in industry show a median starting salary of $505 a month. One man will receive $750, and nine, more than $600. Ten men went into Civil Service at a starting salary of about $370. Approximate median figure for graduates placed by the Business Administration College bureau during the month of of May was $375. The College of Education reported that teachers in elementary and secondary schools start at a median salary of $4000 a year.*

The higher offers to engineers by industrial recruiters, whose eagerness in some cases can be compared only to the college scramble for high school athletes, are leveling off the technical manpower shortage curve and increasing enrollment in technical courses.[1] But what about the graduate entering industry with such an inflated idea of his professional worth? What problems will he meet?

Perhaps it is just as well if he has not read the educational, business, and industrial journals which have been expressing so deep a concern regarding the inadequacy of his training in one direction or another, his personal adjustment to industry, and, incidentally, his probable net worth to the company. Although reports may disagree, they indicate certain aspects of his job of which he should be aware.

High salary for beginners in industry is said at present to be offset by a rapid leveling off that devaluates experience. The men who entered civil service with prospects of a regular increase twice a year, then, may find themselves at the end of five years about as well off as their classmates who went into industry, unless industry has meanwhile corrected this discrepancy.

Industry has also been accused of technical self-impoverishment by making early promotion to management jobs more attractive financially than the slower and less rewarding course for technical promotion.

The Association of Professional Engineers of the Province of Ontario has summarized the answers of 5410 out of 10,416 members as follows:[2]

Years Experience	Technical Work %	Administration %	Supervision %	Sales %
5	45	10	35	10
10	30	20	40	10
15	20	30	40	10
20	15	45	30	10
25	15	50	27	8
30	13	55	27	5

If the table had reported on the first year, it would, no doubt, have shown that most of the 35 per cent of supervisors started in the technical group.

"A fair share of the really highly-paid jobs for the top technical people," is advocated by Dr. O. M. Solandt, who concludes, "It should not be necessary for a top scientist, or engineer, to become a salesman or even an executive in order to get a big salary. His direct contribution to the profitability of the enterprise should justify a salary in the top management bracket."[3]

* This can be considered a 12-month salary, since the summer must be devoted to advanced studies.

But lagging salary increases apparently account for only part of the dissatisfaction of engineers employed technically in industry. The Industrial Relations Center of the University of Chicago compared job satisfactions of 399 engineers and 188 "natural scientists"* in 19 separate working groups in industry, with each other and with non-professional employees in industry. On a centile basis in which very low was 1-10; low, 10-40; average, 40-70; high, 70-90, and very high 90-100, the engineers responded as follows:[4]

Job demands	70
Working conditions	35
Pay	40
Employee benefits	50
Friendliness and cooperation among themselves	72
Interpersonal relationships (supervisor-employee)	47
Technical competence of supervisors	26
Effectiveness of administration	12
Adequacy of communication	38
Security of job and work relations	53
Status and recognition	47
Identification with company	45
Opportunity for growth and advancement	49

The responses of the scientists were somewhat more favorable on some counts. However, "professionals revealed only slightly more favorable attitudes than production workers and factory labor" and "about the same as routine office employees. They were definitely less satisfied than skilled workmen, foremen, salesmen, and management."[4] Nor can the professional groups be dismissed as "misfits," for they seem to get along very well among themselves.

A coast-to-coast survey of five major industries, however, is somewhat more encouraging. Although interviews with 800 engineers revealed almost universal complaints of too much "routine" and "red tape" and too little professional recognition by management, "approximately seven in ten said their company was above average or one of the very best as a place to work."[5] Worth noting is the fact that 74 per cent listed "interesting work" as a major job requirement, indicating perhaps, an industrial waste of potential brain-power and initiative.

Professor Shepard (Sociology) at M.I.T. attributes the frustrations of the engineer in industry to the conflict between scientific study values developed during school and the material values of industry, where "time" and "profit" are often the only criteria.[6]

Perhaps, then, in addition to the financial attractions, the engineer is tempted to resolve this conflict by stepping across into management where he can more closely identify the aims of his job with those of his employer.

Moore and Renck conclude, "There is some evidence that the patterns of administration and organization which characterize industry and which work reasonably well in most other branches of business are inappropriate to research and technical activities."[4] Nevertheless, though the patterns change, the basic personal conflict may continue unless the engineer is fortified by knowledge and judgment to meet this dilemma. How can this be done?

One approach is "a manual or case book in ethics" planned by the ASEE Committee on Ethics[7] because "the canons and codes of ECPD and the several engineering

* Chiefly physicists and chemists, many with advanced degrees.

societies are . . . merely bald statements of maxims" and "have no appeal for the engineering student who should learn something about ethics *although he does not face a personal ethical problem.*"* Here is one of the cases suggested for inclusion: "Is it proper for an employed sales engineer to recommend to a customer the purchase of a competitor's machine when the engineer is convinced that the competitor's machine meets the customer's requirements more nearly than his own company's product?" Is the engineer prepared to decide such a question, or even to discuss it intelligently? A question relating more closely to his recent experience might be: Is cheating in examinations ethical?

Another possible source of frustration may be the teamwork approach to industrial research, adopted by large concerns. Let us assume, first, that our newly graduated engineer with a bachelor's degree and no experience, given his choice, and other factors being equal, would prefer a technical, or creative, career. He is not likely to be assigned to a research team very soon, but his promotion may sooner or later depend on qualities he has displayed during his term of employment.

A director of technical development for a chemical plant, urges "above all, stress teamwork—all the research in the world is worth nothing if you don't know how to take full advantage of it."[8] We read that "historians of the future may well select the development of deliberate creativeness as the most important development of this century," and, by the same author, "It is almost axiomatic that a properly selected research committee can be more effective creatively than the sum of the creativeness of the same persons acting individually."[9]

Perhaps here we should stop to ask, "What is creativity?" and "What is research?"

A new University of Chicago study of creativity has turned up evidence that the creative scientist is a distinguishable personality. He is characterized as "an individualist," "happy when working alone," and one who "likes to initiate his own activities."[10]

Moreover, an interesting distinction has been made by the Supreme Court between research results that are patentable and those which are not,[11] and a report published by the Temporary National Economic Committee, 76th Cong., 3rd Sess. (1941) states: "All inventions derive from common knowledge; they differ in the quality and magnitude of their contributions to the industrial arts. . . . They fall into three rather distinct classes: First, creations which exhibit individual insight; second, derivative processes, worked out by professonal staffs, equipped with laboratory facilities; third, variations upon a basic design such as a dozen workmen would independently contrive. The mark of the first is genius; of the second, professional competence; of the third, mechanical ability. . . ." and, furthermore, "They [patents] are not intended as a reward for the collective achievement of a corporate research organization. . . . Such an advance is the product not of inventive ability but of the financial resources and organizing ability of those who operate the laboratories. . . . Each man is given a section of the hay to search. The man who finds the needle shows no more 'genius' and no more ability than the others who are searching different portions of the haystack."[11]

Degrees of creativity are thus widely distributed, and the engineers who will succeed in teamwork research may not be those who will qualify in the highest degree as creative individualists.

Our graduate, moreover, may discover that even successful team members are often greatly dissatisfied. They complain that they receive no personal and, often, no team recognition, and accuse "management" of taking credit for results produced by the team.[4,5] To recognize this fact—that individual recognition may be slight or lacking entirely, may be another adjustment the young engineer in research will face, and a further incentive to switch to management.

If, however, he is still undaunted, he may find it advisable to study for an advanced degree. This enterprise should be carried on before he has reached the age of greatest creative productivity, said by one authority to be the early thirties.[12] Another states: "Inventive activity is probably highest (on a per capita basis) among those in their late 30's or early 40's, but the output of younger inventors, while scarcer, is likely to be superior."[13] (The possibility that *group* creative productivity may be increased among older workers by keeping the *group identity* young, i.e., by transfers in and out of the group,[14] is the concern of management.)

The man contemplating advanced studies might heed Dr. Lee A. DuBridge, President of the California Institute of Technology, who declares: "Research work is not a series of college courses, it is a way of life. And I do not believe that either a scientist or an engineer can become fully qualified for research and development work unless he has actually lived full time in the atmosphere of a graduate institution, fully immersed in some phase of its research program."[15]

Again, the Chairman of the Board of Arthur D. Little Company, points out the need to "take a new look at the standard requirements for the doctoral thesis, to make sure that in requiring research results that can be packaged and tied at the end of a very short time, we are not diverting the graduate student from more significant research that does not fit the formula. . . . The most critical need is for more of such as I have styled the scientist engineer."[16]

Our engineer, if interested in qualifying for this select designation, must explore in his postgraduate studies at least the fringes of the science world with which later graduates will be much more familiar than he, to judge from proposed curricular shifts. In fact, science and engineering are already showing so many overlapping regions that Professor Adler of M.I.T. (Electrical Engineering) has "noted with alarm the fact that a very large percentage of the really significant recent applications of science were not only conceived, but also quite extensively developed for practical use, by men who were trained as scientists or applied mathematicians, rather than as engineers, . . . the microwave circuitry, the traveling-wave amplifier, . . . the ammonia or cesium 'clock' and the molecular amplifier (Maser). . . ?" While attributing this in part to the "superior" education of the scientist, he concludes, "The fact is that the men responsible for the foregoing developments were of outstanding technical qualiy to begin with, but a most significant point for me now is that *such men were attracted in their formative professional years to the study of science (or of mathematics), rather than to the study of engineering.*[17]

It is possible, then, that, in spite of the fact that the boundary line between "science" and "engineering" is becoming indistinct, the creative individualists find a more flexible and attractive program offered by science. If our engineer has boarded the wrong train, the sooner he becomes aware of it, the better.

(Continued on page 26)

* Emphasis is ours. No doubt, reference is to a *professional* ethical problem. *Ed.*

July, 1957

The TREND

IN ENGINEERING

at the University of Washington

Vol. 9 No. 3

Published quarterly in January, April, July and October, by the Engineering Experiment Station at the University of Washington to reflect the current highlights of its accomplishments and to report progress in its program of investigation and research.

ENGINEERING EXPERIMENT STATION BOARD

Chairman.....Harold E. Wessman
Dean, College of Engineering
Director of the Engineering Experiment Station.....F. Burt Farquharson

DEPARTMENT REPRESENTATIVES

Aeronautical Engineering.....V. M. Ganzer
Chemical Engineering.....R. W. Moulton
Civil Engineering.....R. B. Van Horn
Electrical Engineering.....A. V. Eastman
Forestry.....B. L. Grondal
Geology.....H. A. Coombs
Mechanical Engineering.....B. T. McMinn
Mineral Engineering.....D. R. Pifer

PUBLICATION COMMITTEE

F. B. Farquharson — R. G. Hennes
B. L. Grondal — W. R. Hill

Editor.....Isabel W. Hemenway

PUBLICATION OFFICE

127 More Hall
University of Washington
Seattle 5, Washington

Entered as second-class matter March 7, 1949, at the post office at Seattle, Washington, under the Act of August 24, 1912.

CONTENTS

The Graduate Meets Industry 1

Photogrammetry of Glaciers *A. E. Harrison* . . . 5

Chemical Engineering Student Awarded $9000 Fellowship 8

A Device for Measuring the Swell Pressure of Soil
Bjorn J. Strom, R. G. Hennes 9

National Meeting of A.I.Ch.E. Draws Crowd . . . 12

Dielectric Loading of Waveguides
William V. Kiskaddon, Gedalia Held 13

Process Design of Fixed-Bed Cation-Exchange Units
M. M. David, R. F. Peak 20

Publications and Graduate Theses, College of Engineering: 1956-1957 27

The TAF phototheodolite in use at the Bastile Ridge photogrammetric baseline on Mt. Baker. Kermit Bengtson is operating the instrument; Professor A. E. Harrison is recording data. The tongue of the Coleman Glacier in the distance has been advancing at a rate of more than 300 feet per year.

PHOTOGRAMMETRY OF GLACIERS

A. E. HARRISON

Professor of Electrical Engineering

A. E. Harrison

How would you measure the surface of a glacier precisely? How did an electrical engineer get involved in measurements on glaciers?

The last question is probably the easier to answer. Some people might suspect that a hobby of glacier study is merely an excuse for making repeated trips to the mountains. Actually, the problems involved in measuring the surface of a glacier are good engineering problems (primarily a civil engineering problem), and present a fascinating challenge. Anyone interested in engineering is vitally concerned with measuring things and expressing the results of the measurements accurately and clearly. The opportunity to apply the analytical methods of electrical engineering to the results of a measurement program in the mountains has paid off in enjoyment, accomplishment, and an increased appreciation of the possibilities of photogrammetry as a surveying method.

Before continuing with a discussion of the measurement of glaciers with photogrammetry, it might be a good idea to define a glacier. Not all bodies of permanent ice in the mountains are glaciers. Ice has a peculiar nonlinear property. If the pressure on the ice is below a certain critical value, ice is relatively rigid. When the pressure exceeds this critical value, ice can flow like a plastic material. If more snow falls on a mountaintop during the winter than can be melted during the summer, this excess of accumulation over ablation (melting) will cause the snow to pile higher and higher over a period of years. The lower layers of snow will be compacted into ice. If the thickness of snow and ice is enough to produce the critical pressure, then the ice will begin to move. It is this motion which distinguishes a glacier from other, inactive bodies of ice.

Of course, the transition from inactive ice to a glacier does not occur suddenly, and it would be impossible to make an exact distinction between the barely perceptible motion of thin ice and the more pronounced motion of glacial flow. The smallest glaciers may move only a few feet per year, while a very active glacier can move several feet per day.

This motion allows a glacier to react to changes in climate. If snowfall increases, or if ablation decreases, the increased thickness of ice will produce a greater velocity. The excess of accumulation over ablation at the higher elevations will move down to a lower elevation where the ablation can equal the inflow of ice from above. The glacier attempts to remain in equilibrium with the climate and furnishes a sensitive indicator of climatic changes.

There are several methods of measuring the changes in a glacier and correlating them with climatic factors. Ideally, all of these methods should be utilized in the study of a glacier, but some glaciers are particularly suited to only one form of measurement. The total accumulation of snow at different times during the year may be measured by taking sample cores of the snow from a number of strategic locations. The water content of these cores is determined. The decrease in the level of the surface of the older ice, exposed when the snow has melted from the lower region of the glacier, is also measured at a number of locations. The total precipitation during a year and the ablation loss by melting and evaporation may be determined from these data. The results are known as the glacier budget and are expressed in terms of the change in the mass of the glacier. These measurements must be taken throughout the year. They are usually accompanied by meteorological measurements of temperature, humidity, wind velocity, incoming and outgoing radiation, cloud cover and similar observations. A program of this type is being carried out on the Blue Glacier in Olympic National Park, Washington, during the International Geophysical Year.

Some glaciers have a rough surface, so torn by crevasses that measurements of the type just described are inconvenient. However, the roughness of the surface makes such glaciers particularly suited to accurate measurement of changes in the surface. These measurements yield knowledge of changes in the volume of the ice rather than its mass, but this information is almost as valuable as the mass data on the glacier budget. The techniques of engineering analysis allow a good estimate of the budget from the changes of the surface and a knowledge of the effect of climatic changes on the behavior of the glacier. This conclusion is analogous to the statement in control-systems terminology that the output

FIG. 1. A typical photograph made with the TAF phototheodolite shows the central portion of the Coleman Glacier on Mt. Baker. Fine cross hairs in the rectangles at the top and bottom of the picture and the notched markers on the sides furnish the fiducial marks for determining the aim of the camera.

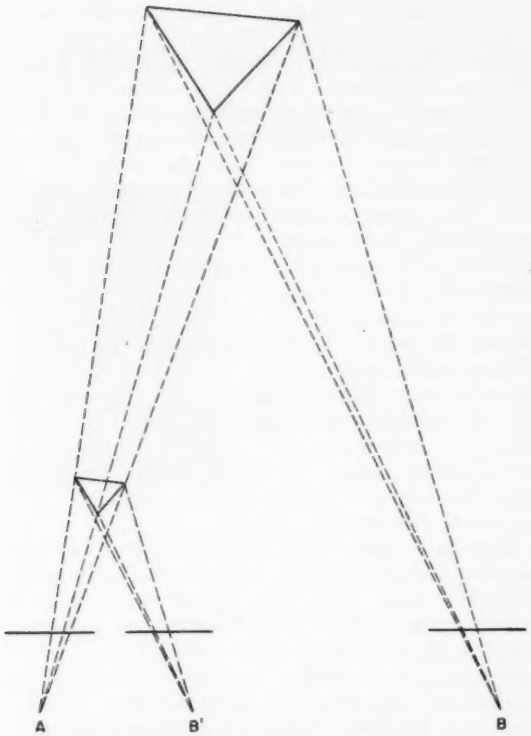

Fig. 2. Viewing the photogrammetric pair of pictures from a closer spacing, AB', instead of the distance between camera lenses, AB, reduces the scale and brings the image closer to the observer.

of a system tells you the input to the system if the "response" of the system is known.

The roughness of a glacier's surface, which makes mass-budget studies or surveying by conventional techniques difficult, is ideally suited to precise measurements of the surface by photogrammetry. The sharp edges of crevasses and seracs, the huge blocks of ice sometimes found on glaciers, provide the objects which are needed for a three-dimensional image of the terrain for either aerial or terrestrial photogrammetry. The latter type of measurement has been applied successfully to the measurement of the Coleman Glacier on Mt. Baker, a 10,778-foot volcanic peak in the northwest corner of the state of Washington. (See frontispiece and Fig. 1.)

A considerably greater impression of depth is required in a stereoscopic image for surveying purposes than is needed for the usual three-dimensional pictures. Ordinary stereo pictures are taken with a camera having two lenses spaced the average distance between a person's eyes. This lens spacing permits distinguishing between distances of several hundred feet, but greater distances appear to be in almost the same distant plane. The illusion of a greater perception of depth can be produced by increasing the spacing between the lenses. This illusion is illustrated by Fig. 2. If the object is photographed from two widely separated points and the pictures are moved together and viewed with a spacing equal to the distance between the viewer's eyes, the object will appear as if reduced in scale and viewed from a closer distance. No distortion will occur, but the object will not appear normal because the viewer is not familiar with such a "cross-eyed" view.

Fig. 3. The TAF phototheodolite is examined by Dr. Richard M. Hubley, Chief Scientist for Arctic Glaciology in the International Geophysical Year program.

This cross-eyed look is exactly what is needed for accurate surveying by photogrammetry. It provides the wide angles of view required for accurate triangulation. The baseline used on Mt. Baker has a length of 660 feet. A single camera with two lenses is obviously out of the question. The desired result is obtained with a precision camera taking two photographs at different times. This camera is known as a phototheodolite. It must have an accurately determined, fixed focal length, four fiducial marks which define the aim of the camera and the center of the picture quite accurately, and a transit for aligning the aim of the camera

with respect to the baseline. One type of phototheodolite is illustrated in Fig. 3.

The position of two or more "control points" which can be seen in the pictures must be accurately known in order to utilize the pictures for photogrammetric surveying. When fixed points on exposed rocks and ridges are used as control points, repeated photogrammetric surveys may be made without resurveying the location of the control points. This plan is very convenient, since the position of the control points must be known with a precision at least ten times greater than that of the baseline, and a resurvey of new control points each year would involve considerable extra equipment. A two- or three-man party is sufficient when the control has already been established.

Pairs of pictures for photogrammetric surveying may be taken at angles other than perpendicular to the baseline. Most plotting equipment is designed to utilize photographs with an aim deviating as much as 30 degrees on either side of perpendicular.

Terrestrial photogrammetry is particularly useful for repeated measurements of small areas in rugged terrain. That description applies to many glaciers, including the Coleman Glacier on Mt. Baker. Its advantages over conventional surveying techniques are emphasized by the fact that a large area can be surveyed by photogrammetry in the same time that is required to establish the location of a single point by triangulation methods. Photogrammetric pictures provide a visual space model of the terrain, and the triangulation is performed by elaborate plotting machines at any convenient later date. The necessity to make more than a few triangulation measurements in the field is eliminated.

A program of measurements on the Coleman Glacier, using conventional surveying techniques, was begun in 1949 by Kermit Bengtson, then an instructor at the Western Washington College of Education at Bellingham. The survey was continued by the author in 1952 and 1953 while Kermit Bengtson was serving in the Navy. Support for the project was granted by the Agnes Anderson Research Fund in 1953 and a TAF phototheodolite was obtained. Kermit Bengtson returned to the University of Washington in 1954 as a graduate student in Chemical Engineering and continued the surveys, using terrestrial photogrammetry. The project is now supported by a five-year grant from the National Science Foundation.

The 660-foot baseline at Mt. Baker is located on Bastile Ridge, an ideal site parallel to the glacier. Three pairs of stereo views are obtained from this baseline. An additional baseline is contemplated near the top of the ridge to give a closer view of Mt. Baker. Another baseline will be required in the bottom of the canyon in order to map the front of the glacier tongue, which has now advanced out of sight from the present baseline on Bastile Ridge.

Results to date indicate that the Coleman Glacier increased its volume 170 million cubic feet between 1954 and 1955. This figure represents an increase of more than six feet in thickness over the lower portion of the glacier, where most of the increase occurred. The average increase over the entire glacier was somewhat less than two feet. Data for the year 1955-1956 are not yet available because the compilation is being done for the University of Washington by the Institute for Photogrammetry in Munich, Germany. This delay is necessary because the plotting machines in this country are intended primarily for making maps from aerial photography and are not available for glacier surveys at a reasonable cost. Machines designed expressly for terrestrial photogrammetry are available, but there are no photogrammetric laboratories in this country equipped with these less expensive machines.

Chemical Engineering Student Awarded $9000 Fellowship

Earl James Davis, graduate student in Chemical Engineering, was awarded the $9000 Leeds and Northrup Fellowship at the ASEE annual meeting in June. Dr. Harold E. Wessman, Dean of the College of Engineering, accepted the award for Mr. Davis at the convention banquet.

The grant, the largest ever received by a University of Washington engineering student, provides $3000 a year for three years to finance his graduate work. It will cover tuition and a substantial cash allowance for Mr. Davis, in addition to funds to reimburse the University for other expenses of the three-year course.

Mr. Davis, 32, who has been conducting a research project on heat-transfer characteristics of liquids, will continue graduate work in this field toward his doctorate.

Leeds and Northrup, manufacturers of engineering instruments, established the fellowship in 1956 to encourage advanced study and research in electrical, mechanical, or chemical engineering. Mr. Davis is the second to receive this award.

A DEVICE FOR MEASURING THE SWELL PRESSURE OF SOIL*

BJORN J. STROM
Graduate Student in Civil Engineering

R. G. HENNES
Professor of Civil Engineering

B. J. Strom

Many compacted soils, notably silt and clay, have a tendency to swell when additional water is made available. Swell is a complicated phenomenon: partly mechanical, as the elastic expansion of the precompressed soil structure sucks available water into the expanding intergranular pores, and partly physical, as water crowds into the pores because of molecular attraction for the surfaces of the solid particles. Chemical action also may be a factor in the swelling process. Similar clays with slight differences in chemical composition can exhibit different swelling characteristics.

High swelling soils may cause the failure of a slope, a road, or an airfield. In some regions buildings are seriously affected by swelling of the underlying soil.

Swelling failures may be prevented either by cutting off the supply of water to the soil or by loading the soil with a sufficient surcharge to neutralize the expansive forces, or the swelling soil may be excavated and replaced with better material. But, in any event, to forestall failure the soil's tendency to swell must be found and evaluated.

The swelling tendency of soil is generally expressed in terms of swell pressure, which is the pressure required to restrain a compacted sample from expanding in the presence of free water. There are many methods of measuring swell pressure. Generally, the apparatus consists of a cylindrical mold in which the soil is compacted and contained during the test, and an attachment for measuring the expansion taking place. Perhaps the most widely used apparatus is the Hveem swell device (Fig. 1). It was developed at the Division of Highways of the California Department of Public Works, and has been adopted quite generally by the Western States.

In order to evaluate present techniques and to throw more light on the problem, a new device was developed which eliminates the rigid lateral restraint and wall friction characteristic of confinement in a metal mold. The new apparatus is shown in Fig. 2. It consists of a pressure container, a base plate, a top plate, and a rubber membrane shaped like a top hat. The pressure container has a pressure gage, a tire valve, and a pipe plug. The hole where the pipe plug fits may be used to connect the chamber to an air supply. The bottom is open and is pressed down on the base plate with the flange of the rubber membrane in between, as shown in the sketch.

R. G. Hennes

The base plate is about 8 inches square. It contains a porous stone, 3½ inches in diameter, which is set down into the plate flush with the surface. Two channels through the base plate lead to the porous stone. A wye made from ⅝-inch plastic tubing leads to these channels. (The plastic tubing was quite easily welded by the use of an electric soldering iron.)

There are four studs in the base plate for clamping down the pressure container, providing a pressure-tight connection.

The rubber membrane was fabricated from 0.012-inch thick dental dam and two ⅛-inch thick rubber rings. The membrane consists of two layers of this dental dam glued together with rubber cement.

As finally developed, the procedure consisted of mixing a soil sample with the desired amount of water, tempering it for 24 hours, compacting it in a kneading compactor, and then introducing the specimen into the swell device. Compaction was accomplished in the kneading compactor adopted by the Triaxial Institute.[1] The sample was contained in a cylindrical mold of 4-inch inside diameter while being compacted. It was then removed from the mold and placed on the base plate, centered over the porous stone. The rubber membrane was pulled down over the sample, and the pressure chamber was clamped down on the base plate so that the flange of the membrane acted as a gasket.

The sample could be surrounded by air or water in the pressure chamber. It was assumed at the outset

* Condensed and arranged from the M.S.C.E. thesis of Bjorn Strom (1957). Mr. Strom's research was conducted under the supervision of Professor Hennes.

[1] "The Triaxial Institute Kneading Compactor," by Martin Ekse, *The Trend in Engineering*, Vol. 4, No. 1 (January, 1952).

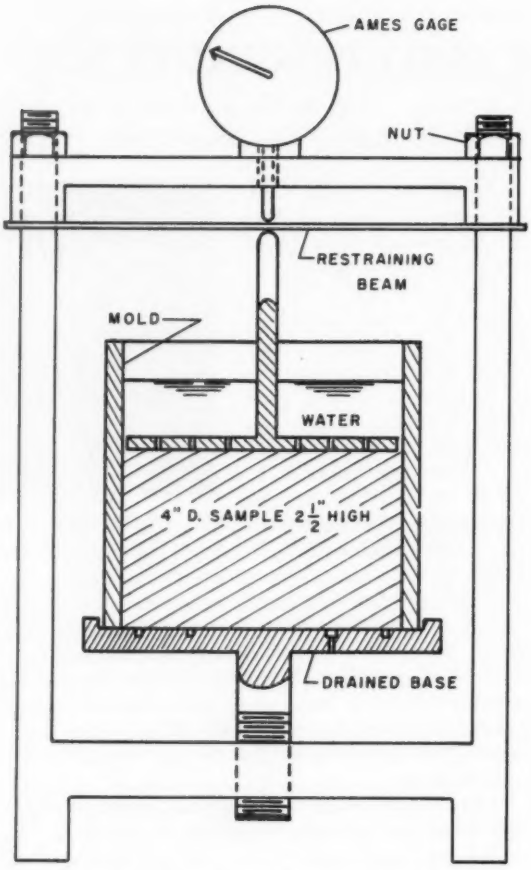

FIG. 1. HVEEM SWELL PRESSURE DEVICE

of the investigation that a sample subjected to a pressure equal to the maximum swell pressure would not absorb water. Under such circumstances the specimen would be in equilibrium with its surroundings, at constant volume. This assumption implies that the absorption of water and the volume expansion are equivalent, so that no absorption could occur when volume expansion was inhibited by an external pressure equal to the swell pressure.

Several samples made at the same moisture content and at the same degree of compaction were tested under different confining pressures. A sample confined by a pressure greater than the maximum swell pressure should take up no water, and the ones tested at lower confining pressures would absorb water according to the applied pressure. For the general case, where there was no sample surrounded by a pressure exactly equal to the swell pressure, this value would be scaled from a plot of water absorbed against applied pressure.

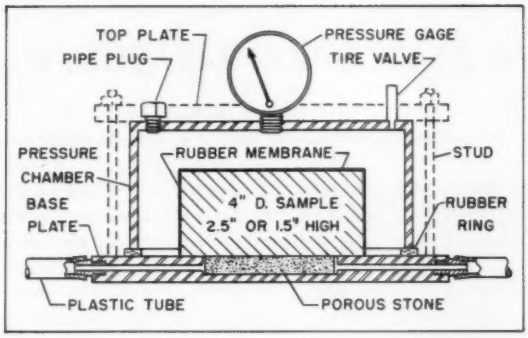

FIG. 2. SECTION VIEW OF NEW DEVICE

A series of samples was tested to probe these assumptions. The samples were made up of a local silty clay with a liquid limit of 43, at an initial water content of 15 per cent.

The results of these tests indicated flaws either in the assumption or in the test procedure. When the amount of absorbed water was plotted against the applied pressure, the resulting curve was highly irregular and showed no appreciable decrease in absorption with increasing external pressure. The applied pressure varied from 5 psi to 30 psi. The swell pressures obtained by the Hveem device do not exceed 10 psi as a rule, so it seemed reasonable that a break in the curve would occur at a pressure lower than 30 psi. Presumably the residual capillary pressure in the specimen was replaced by an external confining pressure without measurable restriction of the volumetric expansion due to swell.

In the foregoing tests external pressure was provided by an air compressor and controlled by a pressure-regulating valve in the line.

Subsequently, a different test procedure, which seemed to be more successful, utilized the expansion of the soil to build up the pressure in the chamber. The pressure chamber was filled with water under pressure so that there was an initial pressure of about 2 psi. When the sample was exposed to water, it swelled until the swell pressure was reached. The pressure then remained constant in the chamber, and the swell pressure was read directly off the gage. While the chamber was being filled with water, the pipe plug was removed. Water was introduced through the tire valve, and the air was permitted to escape through the pipe-plug hole. When the chamber was full and all the air had been flushed out, the pipe plug was replaced. The water line was not disconnected from the valve until the pressure in the chamber was between 2 psi and 3 psi. This initial pressure served to close the rubber membrane tightly against the sample and to take up any slack that might be in the system. The wye was then

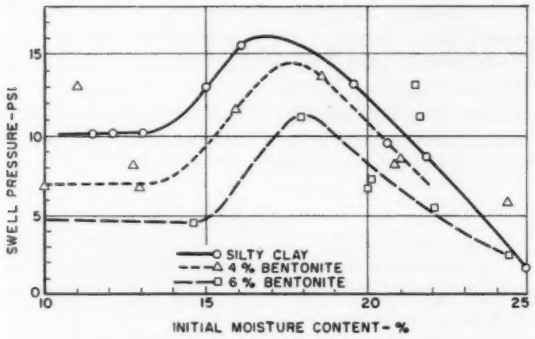

FIG. 3. SWELL PRESSURE VS. INITIAL MOISTURE FOR DIFFERENT SOILS

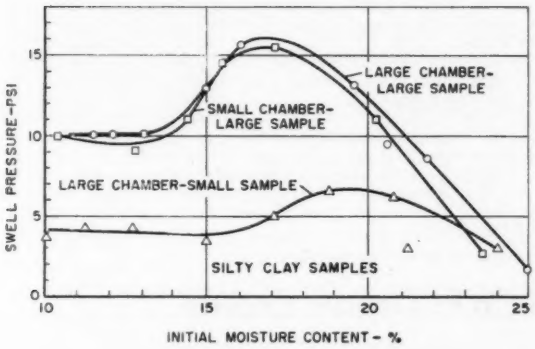

FIG. 4. SWELL PRESSURE VS. INITIAL MOISTURE FOR DIFFERENT SAMPLES AND PRESS CHAMBERS

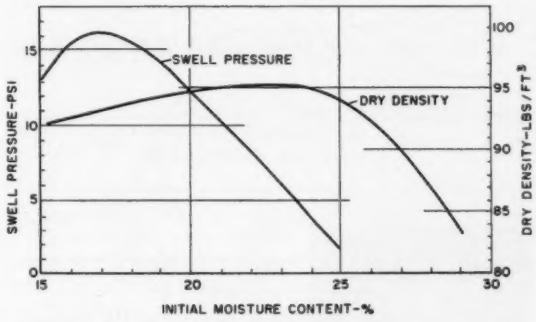

FIG. 5. COMPARISON OF SWELL PRESSURE AND OPTIMUM DENSITY FOR SILTY CLAY

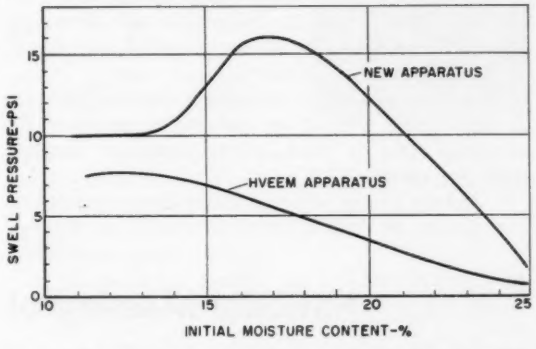

FIG. 6. COMPARISON OF HVEEM DEVICE AND NEW DEVICE FOR SILTY CLAY

filled with water and the sample was allowed to swell for 16 hours before the swell pressure was read. It was found that the sample generally developed between 90 per cent and 100 per cent of its ultimate swell pressure in less than 16 hours. The temperature was kept fairly constant during the test since it was found that an appreciable temperature variation would cause a large pressure change whenever air bubbles were present in the chamber.

In this series of tests two sizes of samples were used, some of them 2.5 inches high, and the others 1.15 inches high, but all with a circular base of 4-inch diameter. For the large samples three different soils were used. One was the silty clay previously mentioned, another was the silty clay with 4 per cent of bentonite clay added, the third, a silty clay with 6 per cent bentonite.

The results of these tests are shown by Figs. 3 and 4.

The curves of Fig. 3 are different from the curves obtained by the Hveem device, but it seems that their shape is reasonable. The swell pressure is low for both the extreme dry and extreme wet conditions.

The swelling depends partly on the compaction of the soil. Figure 5 shows that the dry samples attained a lesser degree of compaction than did the ones of intermediate wetness. The extremely wet ones were also poorly compacted. This and the fact that a wet sample will take up little water make for low swell pressures at either end of the curve.

Figure 6 compares the curves for the silty clay for the Hveem apparatus with those of the new device. It seems that differences between results from the two devices may be explained by wall friction and by the different conditions of confinement. Assuming that swell pressure is reduced by an amount approximately proportional to the amount of wall friction, the curve on Fig. 7 would indicate the relative magnitudes of the amounts to be added to the Hveem curve to compensate for wall friction. This correction would make the two curves more alike. In the course of the experimentation it was found that the samples were subjected to a greater degree of confinement in the new device than in the Hveem apparatus. At one pressure the expansions were 0.6 per cent for the new method and 6 per cent for the other. Comparison of large and small samples

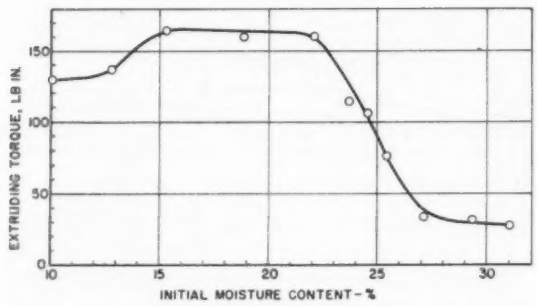

FIG. 7. EXTRUDING TORQUE VS. INITIAL WATER CONTENT

in the new device disclosed that a sample with a greater degree of confinement would have a higher swell pressure. From this it would seem that a large part of the unexplained differences still remaining after compensation for friction should be attributed to variation in confinement.

This new method is somewhat slower than the methods being used at present, but it possesses the advantage that it more nearly measures absolute swell pressures.

A feature of the new apparatus is its versatility. The degree of confinement can easily be modified by connecting the pressure chamber to an air-filled tube. The volume of the tube controls the amount of expansion permitted to the soil. The product of this investigation has been a new apparatus, some plotted data, and some speculation regarding experimental methods. Perhaps this last item may be of most interest to the reader.

BIBLIOGRAPHY

1. ALLEN, HAROLD, and JOHNSON, A. W., "The Results of Tests to Determine the Expansive Properties of Soils," *Proceedings,* Highway Research Board, Vol. 16, 1936.
2. FINN, W. D., "Swelling of Soil," M.S. Thesis, University of Washington, 1957.
3. HVEEM, F. N., and CARMANY, R. M., "The Factors Underlying the Rational Design of Pavements," *Proceedings,* Highway Research Board, Vol. 28, 1948.
4. KELLY, HAL J., STRANDBERG, KARLE G., and HARRIS, HENRY M., "Use of Washington Bentonite as a Hydro-Seal," *The Trend in Engineering,* Vol. 8, No. 4 (Oct., 1956).
5. LECLERC, R. V., "How to Handle Swelling Soils," *Proceedings,* 7th Northwest Conference on Road Building, February 18, 1954.
6. SEED, H. B., LUNGREN, R., and CHAN, C. K., "The Effect of Compaction Methods on the Stability and Swell Pressure Characteristics of Soils," *Proceedings,* 33rd Annual Meeting of the Highway Research Board, January, 1954.
7. TSCHEBOTARIOFF, G. P., *Soil Mechanics, Foundations, and Earth Structures,* New York, McGraw-Hill Book Co., Inc., 1951.

National Meeting of A.I.Ch.E. Draws Crowd

THE 36TH NATIONAL MEETING of the American Institute of Chemical Engineers, which took place in Seattle, June 9-12, with headquarters at the Olympic Hotel, drew almost 500 chemical engineers from all parts of the United States. The meeting was the first of its kind held in the Pacific Northwest.

Faculty members of the Chemical Engineering Department of the University, headed by Dr. R. W. Moulton, took an active part in making arrangements for the convention and contributed to the program.

Dr. M. M. David, treasurer of the executive committee, also headed the finance committee. Dr. A. L. Babb was chairman of the registration committee, and Dr. L. N. Johanson was on the publicity committee. Dr. J. L. McCarthy was co-chairman of the symposium on "Chemical Engineering in the Pulp and Paper Industry," and Dr. R. W. Moulton presided at the second session of the symposium on "Chemical Engineering Data and Calculation Methods."

Taking part in the symposium on "Electrochemical Engineering," Dr. Harold T. Fullam (graduate student) and Dr. Moulton presented a paper on "Metallic Borides and Silicides by Fused Salt Electrolysis."

D. M. Himmelblau (graduate student) and Dr. A. L. Babb contributed "Kinetic Studies of Carbonation Reactions Using a Radioactive Tracer" to Technical Session No. 5, and on the same program, Dr. M. M. David presented a paper on "Equilibrium in the System Cu^{++}-Na^{+}-Dowex 50," the co-author being H. C. Subba Rao, recently a graduate student and now with General Petroleum Corporation, Los Angeles.

L. A. Lundberg, former graduate student, was on the Pulp and Paper Industry program with "Continuous Production of Wood Cellulose Pulp."

Members from ten other universities and research institutes located from Connecticut to Texas and from Washington to Florida appeared on the program. Research reports from large industries, including E. P. du Pont de Nemours, General Electric, Dow Chemical Company, Crown-Zellerbach, Shell and Standard Oil Companies, and Johns-Manville, emphasized the extensive research programs being conducted by such firms in the areas of Chemical Engineering, alone.

John E. Kaufmann, of the Atomic Energy Commission, presided at the symposium which discussed "Industry's Role in University Programs on Nuclear Engineering."

The 1958 meeting, to be held in Philadelphia, will celebrate the 50th Anniversary of the American Institute of Chemical Engineers.

DIELECTRIC LOADING OF WAVEGUIDES*

WILLIAM V. KISKADDON
Research Assistant
Engineering Experiment Station

GEDALIA HELD
Associate Professor of
Electrical Engineering

W. V. Kiskaddon

Introduction

Periodic loading in waveguides has become important in many applications, most of them centered around the property of these loaded guides to slow a wave down to a velocity less than the speed of light. For example, in electron beam devices a phase velocity near the velocity of an electron beam is desired. Another use of a loaded guide is to provide a desired phase shift. Metal irises are generally used for loading.

Laminated dielectrics have been used for antenna housings, or radomes, for many years. The thickness of these housings is generally of the same order of magnitude as the wavelength of the radiation involved. Thus, the problems of reflection, absorption of power by the radome walls, and diffraction are present in the design of radomes.

An incident TEM wave, or plane wave, has been assumed in most of the analyses and design techniques on this problem up to the present time. The radome is actually close enough to the antenna so that the near zone fields should be considered; that is, the incident wave has an E field component in the direction of propagation. A TM mode propagating in a guide loaded with periodic variations of dielectric constant would be a first approximation of the study of laminated sheets in the near zone field in free space.

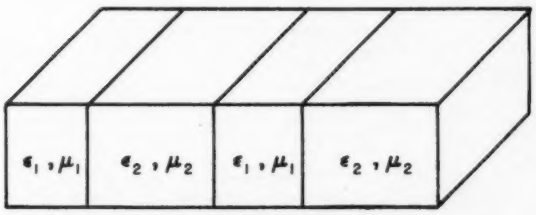

FIG. 1. DIELECTRIC LOADED WAVEGUIDE

This study was undertaken to determine the properties of a guide with periodic dielectric loading consisting of alternate regions filled with different dielectric plates perpendicular to the axis of the guide, as shown in Fig. 1, and to explore possible uses of such a guide. Propagation and impedance characteristics of the loaded guide were to be studied. This investigation would also be a first step in the larger problem of radome design.

G. Held

Theory

A transmission matrix for a four-terminal network, shown in Fig. 2, can be defined as follows:[1,2]

$$\begin{aligned} b_2 &= T_{11}\,a_1 + T_{12}\,b_1 \\ a_2 &= T_{21}\,a_1 + T_{22}\,b_1 \end{aligned} \quad ; \text{ or, } \begin{bmatrix} b_2 \\ a_2 \end{bmatrix} = [\mathbf{T}] \begin{bmatrix} a_1 \\ b_1 \end{bmatrix}. \qquad (1)$$

If another four-terminal network with transmission matrix $\mathbf{T}_2$ is added to the first, the total resultant matrix is the matrix product of $\mathbf{T}_1$ and $\mathbf{T}_2$ in the reverse order. In general, for n networks cascaded together,

$$(\mathbf{T}) = (\mathbf{T}_n)\,(\mathbf{T}_{n-1}) \ldots\ldots \mathbf{T}_1. \qquad (2)$$

FIG. 2. FOUR-TERMINAL NETWORK

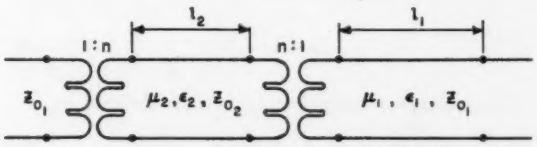

FIG. 3. EQUIVALENT CIRCUIT OF TYPICAL SECTION OF LOADED GUIDE

* This work was supported in part by the Boeing Airplane Company, Seattle.

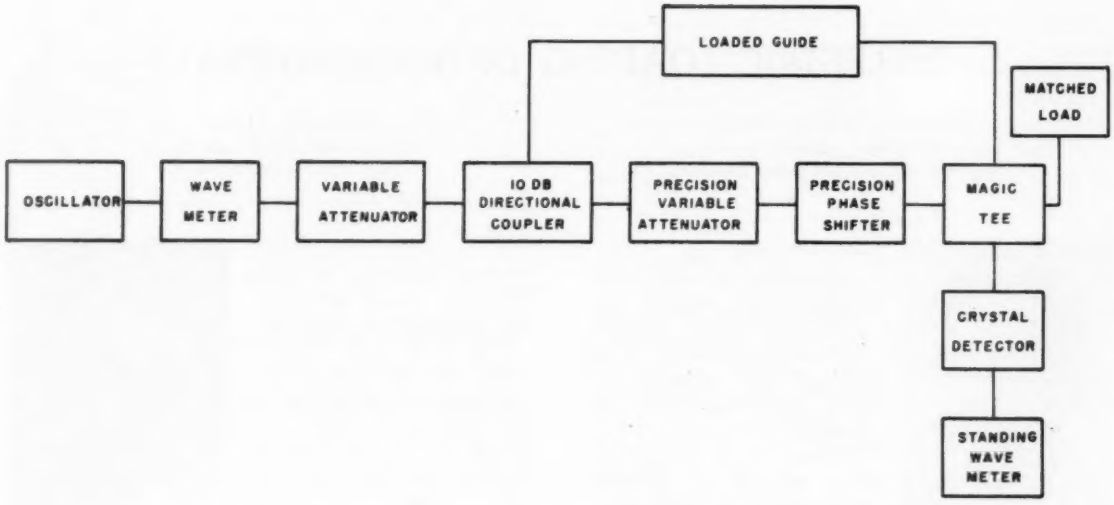

FIG. 4. SCHEMATIC DIAGRAM FOR MEASUREMENT OF PHASE SHIFT

A transfer constant can be defined for this network as follows:

$$b_2 = a_1 e^{-j\theta} . \tag{3}$$

Solving Eq. 1 for b_2 in terms of a_1, with a_2 set equal to zero, yields:

$$b_2 = \frac{T_{11}\,T_{22} - T_{12}\,T_{21}}{T_{22}}\, a_1 .$$

By the principle of reciprocity, the determinant of $\mathbf{T}$ is unity, so that

$$b_2 = \frac{1}{T_{22}}\, a_1 . \tag{4}$$

From Eqs. 3 and 4,

$$e^{j\theta} = T_{22} :$$

or,

$$\cos\theta = \mathrm{Re}\,(T_{22}) . \tag{5}$$

The reflection coefficient for the network is defined as $\rho = b_1/a_1$. If a_2 is set equal to zero, it can be shown from Eqs. 1 that

$$\rho = -\frac{T_{21}}{T_{22}} . \tag{6}$$

The voltage standing wave ratio is defined as

$$\mathrm{VSWR} = \frac{1+|\rho|}{1-|\rho|} . \tag{7}$$

The equivalent circuit of a typical section of the loaded rectangular guide with dimensions a and b is shown in Fig. 3.[1,2]

The transmission matrices for the individual elements of the typical section are:

$$\mathbf{T}_1 = \begin{pmatrix} n+\frac{1}{n} & n-\frac{1}{n} \\ n-\frac{1}{n} & n+\frac{1}{n} \end{pmatrix} ; \quad \mathbf{T}_2 = \begin{pmatrix} e^{-j\beta_2 l_2} & 0 \\ 0 & e^{j\beta_2 l_2} \end{pmatrix} ;$$

$$\mathbf{T}_3 = \begin{pmatrix} n+\frac{1}{n} & \frac{1}{n}-n \\ \frac{1}{n}-n & n+\frac{1}{n} \end{pmatrix} ; \quad \mathbf{T}_4 = \begin{pmatrix} e^{-j\beta_1 l_1} & 0 \\ 0 & e^{j\beta_1 l_1} \end{pmatrix} ;$$

where

$$n^2 = Z_{0_2}/Z_{0_1} ;$$

$$Z_{0_{\mathrm{TE}_i}} = \frac{\mu_i \omega}{\beta_i} ; \qquad (i = 1, 2)$$

$$Z_{0_{\mathrm{TM}_i}} = \frac{\beta_i}{\omega \epsilon_i} ;$$

$$\beta_i = \sqrt{\omega^2 \mu_i \epsilon_i - \left(\frac{n\pi}{a}\right)^2 - \left(\frac{m\pi}{b}\right)^2} .$$

Combining these, using Eq. 2 and substituting for n for a TE mode, yields:

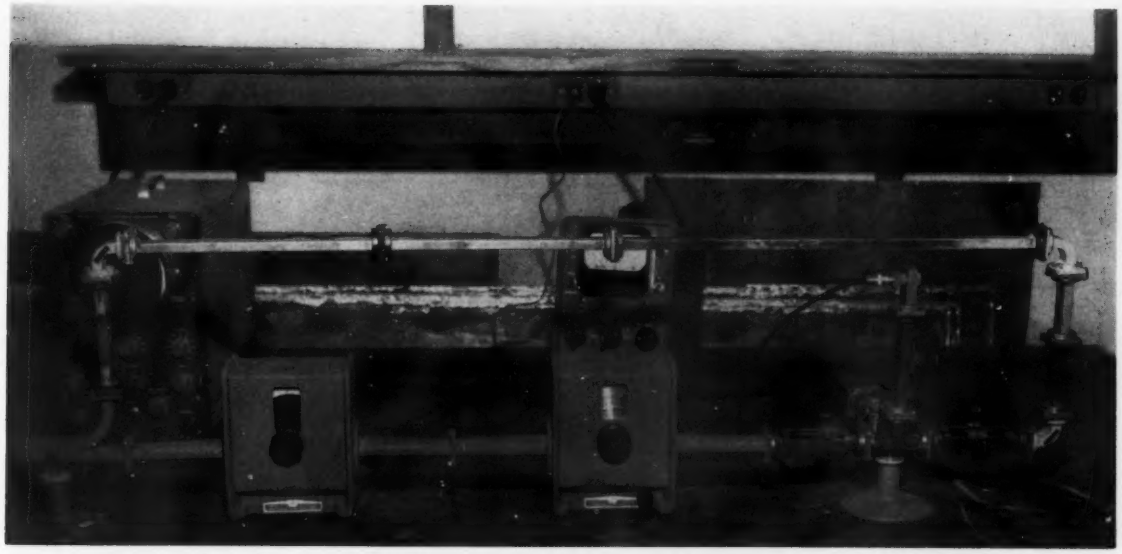

FIG. 5. EQUIPMENT FOR MEASURING PHASE SHIFT

$$T_{11}=e^{-j\theta_1}\left[\cos\theta_2-j\,\frac{\beta_1^2+\beta_2^2}{2\beta_1\beta_2}\sin\theta_2\right]; \tag{8}$$

$$T_{12}=j\,\frac{\beta_2^2-\beta_1^2}{2\beta_1\beta_2}\,e^{-j\theta_1}\sin\theta_2\,; \tag{9}$$

$$T_{21}=-j\,\frac{\beta_2^2-\beta_1^2}{2\beta_1\beta_2}\,e^{j\theta_1}\sin\theta_2\,; \tag{10}$$

$$T_{22}=e^{j\theta_1}\left[\cos\theta_2+j\,\frac{\beta_1^2+\beta_2^2}{2\beta_1\beta_2}\sin\theta_2\right]; \tag{11}$$

where

$\theta_i=\beta_i l_i\,;\qquad (i=1,2)$

β_i = propagation constant in region filled with dielectric (i);

l_i = length of region filled with dielectric (i).

The propagation constant of the structure can be found immediately, using Eq. (5):

$$\cos\beta_{TE}(l_1+l_2)=\cos\theta_1\cos\theta_2-\frac{\beta_1^2+\beta_2^2}{2\,\beta_1\beta_2}\sin\theta_1\sin\theta_2\,. \tag{12}$$

The $\mathbf{T}$ matrix for N sections of loading can be found by raising the $\mathbf{T}$ matrix of the typical section to the Nth power, using the Cayley-Hamilton theorem. The results of this operation[3] are:

$$T_{11}^N=\frac{T_{11}\sinh N\Gamma'-\sinh(N-1)\Gamma'}{\sinh\Gamma'}\,; \tag{13}$$

$$T_{12}^N=T_{12}\,\frac{\sinh N\Gamma'}{\sinh\Gamma'}\,; \tag{14}$$

$$T_{21}^N=T_{21}\,\frac{\sinh N\Gamma'}{\sinh\Gamma'}\,; \tag{15}$$

$$T_{22}^N=\frac{T_{22}\sinh N\Gamma'-\sinh(N-1)\Gamma'}{\sinh\Gamma'}\,; \tag{16}$$

where

$$\Gamma'=\cosh^{-1}\left(\frac{T_{11}+T_{22}}{2}\right).$$

Combining Eqs. 15, 16, and 6, the reflection coefficient for a loaded guide with N sections of loading is

$$\rho_{N_{TE}}=\frac{\dfrac{\beta_2^2-\beta_1^2}{\beta_1\beta_2}\sin\theta_2\,e^{j\theta_1}}{2\cos\theta_2\sin\theta_1+\dfrac{\beta_1^2+\beta_2^2}{\beta_1\beta_2}\sin\theta_2\cos\theta_1+j\,2\cot N\Gamma\sin\Gamma}\,, \tag{17}$$

where

$$\Gamma=\cos^{-1}\left[\cos\theta_1\cos\theta_2-\frac{\beta_1^2+\beta_2^2}{2\,\beta_1\beta_2}\sin\theta_1\sin\theta_2\right]. \tag{18}$$

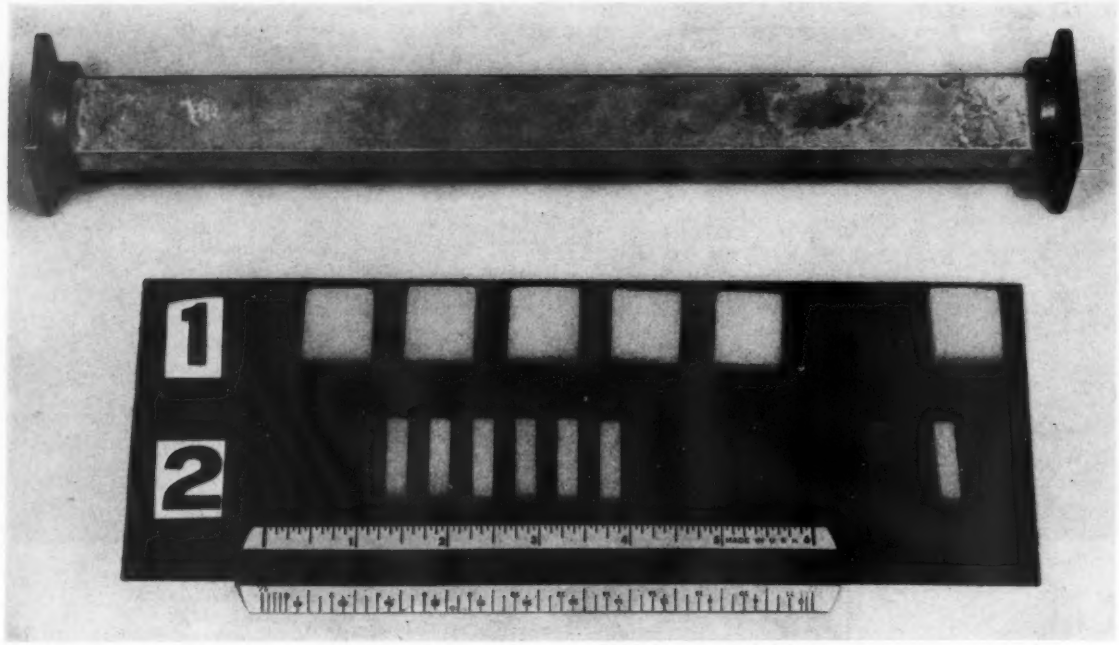

FIG. 6. TYPICAL LOADING OF DIELECTRIC LOADED WAVEGUIDE

Similar expressions for propagation constant and reflection coefficient may be derived for TM modes:

$$\cos\beta\,(l_1+l_2)=\cos\theta_1\cos\theta_2-\frac{(\epsilon_1\beta_2)^2+(\epsilon_2\beta_1)^2}{2\,\beta_1\beta_2\,\epsilon_1\epsilon_2}\sin\theta_1\sin\theta_2\;; \tag{19}$$

$$\rho_{N_{TM}}=\frac{\dfrac{(\epsilon_2\beta_1)^2-(\epsilon_1\beta_2)^2}{\epsilon_1\epsilon_2\,\beta_1\beta_2}\sin\theta_2\,e^{j\theta_1}}{2\cos\theta_2\sin\theta_1+\dfrac{(\epsilon_2\,\beta_1)^2+(\epsilon_1\,\beta_2)^2}{\epsilon_1\epsilon_2\,\beta_1\beta_2}\sin\theta_2\cos\theta_2+j\,2\cot N\Gamma\sin\Gamma}\;; \tag{20}$$

where:

$$\Gamma_{TM}=\cos^{-1}\left[\cos\theta_1\cos\theta_2-\frac{(\epsilon_1\beta_2)^2+(\epsilon_2\beta_1)^2}{2\,\beta_1\beta_2\,\epsilon_1\epsilon_2}\sin\theta_1\sin\theta_2\right]. \tag{21}$$

Note that the expression for ρ is exact only if ϵ_1 is the same as the dielectric constant of the feed guide. Otherwise, the **T** matrix of the first section would not be the same as the typical section **T** matrix, since the first transformer would have a different turns ratio. The **T** matrix for the loaded guide with N sections would then be

$$\mathbf{T}_N=(\mathbf{T}_t)^{N-1}\,(\mathbf{T}_1)\,.$$

The $\sin\theta_2$ term in the numerator of ρ is a major factor in determining the maximum value that ρ can attain. If $\sin\theta_2$ is zero, there will be no reflection for any number of sections of loading. This result would be expected from transmission-line theory, since the length l_2 is a multiple of one-half wavelength when this condition is satisfied.

Experimental Procedure

Power transmission, phase shift, and reflection coefficient, as functions of ϵ_1, ϵ_2, l_1, l_2, and N, were measured for a dielectric loaded guide to determine the validity of the foregoing equations. Montgomery[4] discusses various techniques of measurement and sources of error for all of these procedures. The phase-shift measuring technique used is shown as one method of measurement of dielectric constant.

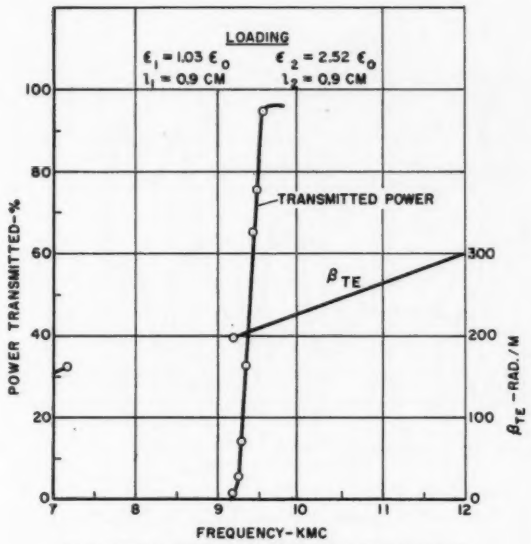

FIG. 7. TRANSMITTED POWER VS. FREQUENCY
Waveguide No. 1

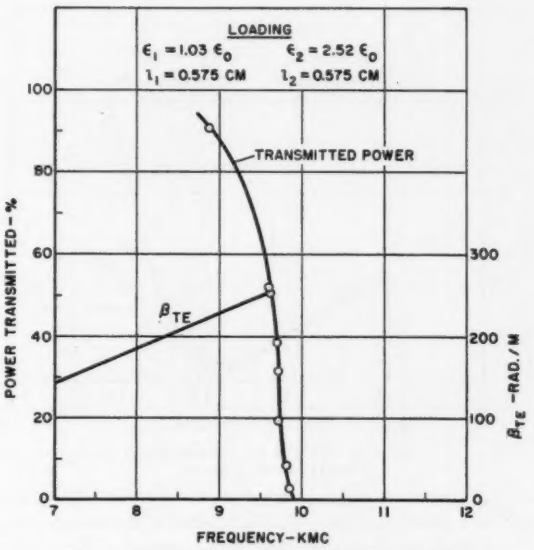

FIG. 9. TRANSMITTED POWER VS. FREQUENCY
Waveguide No. 3

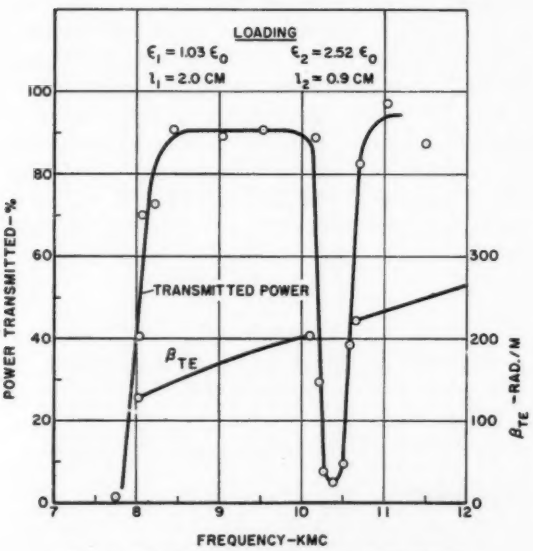

FIG. 8. TRANSMITTED POWER VS. FREQUENCY
Waveguide No. 2

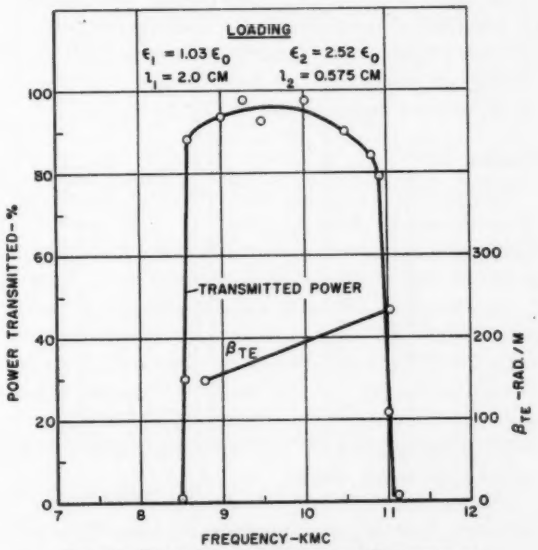

FIG. 10. TRANSMITTED POWER VS. FREQUENCY
Waveguide No. 4

Since all measuring equipment on hand is designed for the TE_{10} mode propagating in a rectangular guide, the first laboratory work was done using this mode. Measurements to validate Eqs. 20 and 21 for the TM mode are now in progress as part of another research project at the University, the TM mode being the one that approaches the radome problem.

The setup used to measure the phase shift through the loaded guide is shown in Fig. 4. The magic-tee was used as a bridge to compare the signals in the two incoming arms. The standing wave meter was connected to the arm of the magic-tee that has no output when the phase and magnitude of the incoming signals are equal. The attenuator and phase shifter were adjusted for a minimum reading on the standing wave meter, with an empty guide in the upper branch. The phase-shifter setting was noted. The empty guide was replaced by a loaded guide

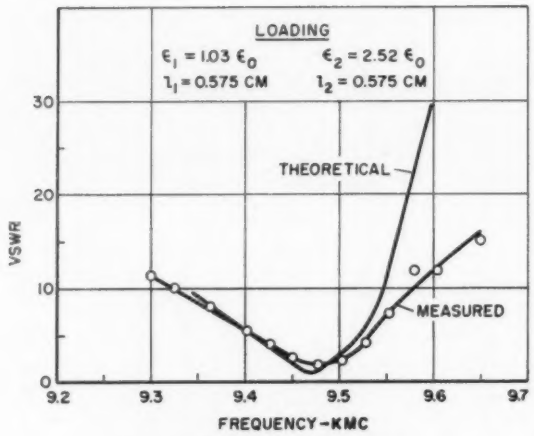

FIG. 11. VSWR VS. FREQUENCY
10 sections of loading

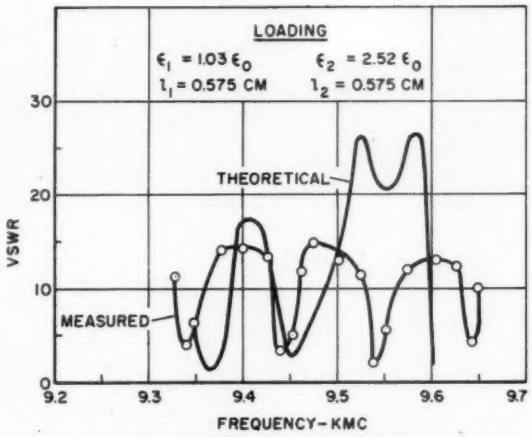

FIG. 12. VSWR VS. FREQUENCY
49 sections of loading

and the phase shifter and attenuator were readjusted for a null on the standing wave meter. The difference in phase-shifter settings is a measure of the phase shift in the loaded guide. Since the addition of $2n\pi$ radians does not change the apparent effect, the exact phase shift must be determined by estimating or predicting the actual value. A photograph of the setup is shown in Fig. 5.

Results

Polystyrene ($\epsilon_2=2.52$) and polyfoam ($\epsilon_1=1.03$) were chosen for loading. Both of these materials have low losses at microwave frequencies. A photograph of typical loading is shown in Fig. 6. Line 1 is an example of five sections of loading with $l_1=2.0$ and $l_2=0.9$ cm. Line 2 shows six loaded sections with $l_1=0.575$ and $l_2=0.575$ cm. Individual blocks of each component of the loaded section are shown at the extreme right of each line. The loaded guide was a regular piece of 0.4-by-0.9-inch guide filled with the dielectric blocks.

The variations of β_{TE} with frequency for different dielectric loaded guides propagating the TE_{10} mode are shown in Figs. 7, 8, 9, 10. The bandpass characteristics of the dielectric loaded guide are apparent. Propagation ceases when $\cos\beta_{TE}(l_1+l_2)$ becomes larger than one and β_{TE} becomes imaginary. This condition is possible when the angles θ_1 and θ_2 are such that the terms of Eq. 11 numerically add.

The cutoff characteristics of these loaded guides were checked for loading with $l_1=l_2=0.9$ cm, $l_1=l_2=0.575$ cm, $l_1=2.0$ and $l_2=0.9$ cm, and $l_1=2.0$ and $l_2=0.575$ cm, by measuring the percent power transmitted through the loaded guides. The length of the loaded guide was a deciding factor in how much attenuation is accomplished. For example, for $l_1=2.0$ and $l_2=0.9$ cm, with a loaded guide length of 60 cm, the power dropped to 20 per cent in the stop band. With 30-cm length, 80 per cent of the power was transmitted. The results of measurements of transmitted power appear in Figs. 7, 8, 9, and 10, where the variations of the ratio of incident to transmitted power are shown, along with the variations of β_{TE} with frequency. The sharp cutoff characteristics of the loaded guides that were observed in the laboratory are apparent in these curves.

TABLE I
RESULTS OF PHASE SHIFT MEASUREMENTS

Frequency and Loading	L (cm)	$\Delta\theta$	
		Theoretical	Measured
$f=9.375$ kmc $l_1=2.0$ cm $l_2=0.9$ cm	52.2 29.0 23.2	$235+6\pi$ $11.5+4\pi$ $225+2\pi$	$240.5+2n\pi$ $17.7+2n\pi$ $220+2n\pi$
$f=9.375$ kmc $l_1=2.0$ cm $l_2=0.575$ cm	48.9 28.3 20.6	$179+4\pi$ $160+2\pi$ $18.9+2\pi$	$178+2n\pi$ $165+2n\pi$ $19.8+2n\pi$
$f=9.0$ kmc $l_1=2.0$ cm $l_2=0.9$ cm	52.2 29.0 23.2	$176+6\pi$ $338+2\pi$ $198+2\pi$	$179+2n\pi$ $343+2n\pi$ $194+2n\pi$
$f=9.5$ kmc $l_1=2.0$ cm $l_2=0.9$ cm	52.2 29.0 23.2	$257+6\pi$ $22.7+4\pi$ $232+2\pi$	$265+2n\pi$ $29.6+2n\pi$ $235+2n\pi$
$f=8.8$ kmc $l_1=2.0$ cm $l_2=0.9$ cm	52.2 29.0 23.2	$152+6\pi$ $324+2\pi$ $187+2\pi$	$144+2n\pi$ $328+2n\pi$ $175+2n\pi$

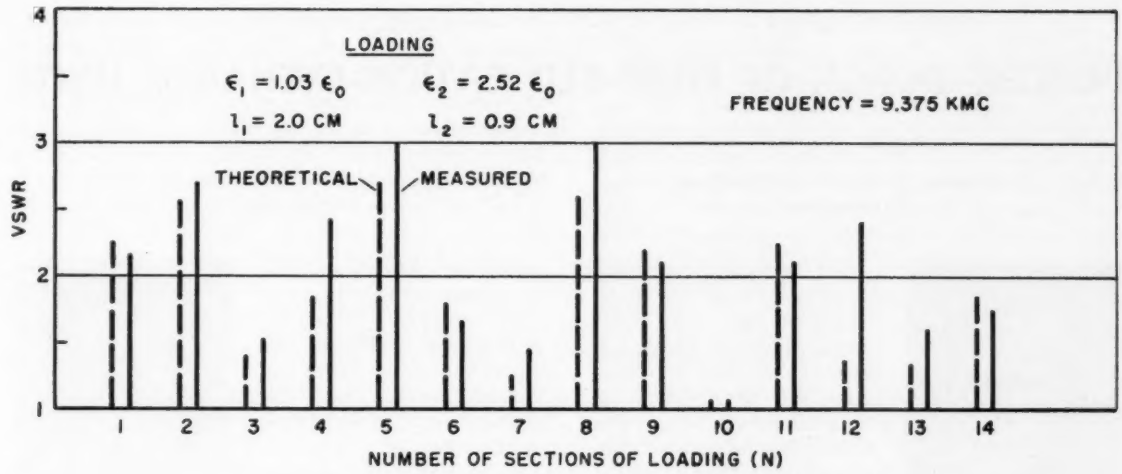

FIG. 13. VSWR VS. NUMBER OF SECTIONS OF LOADING (l_2=0.9 cm)

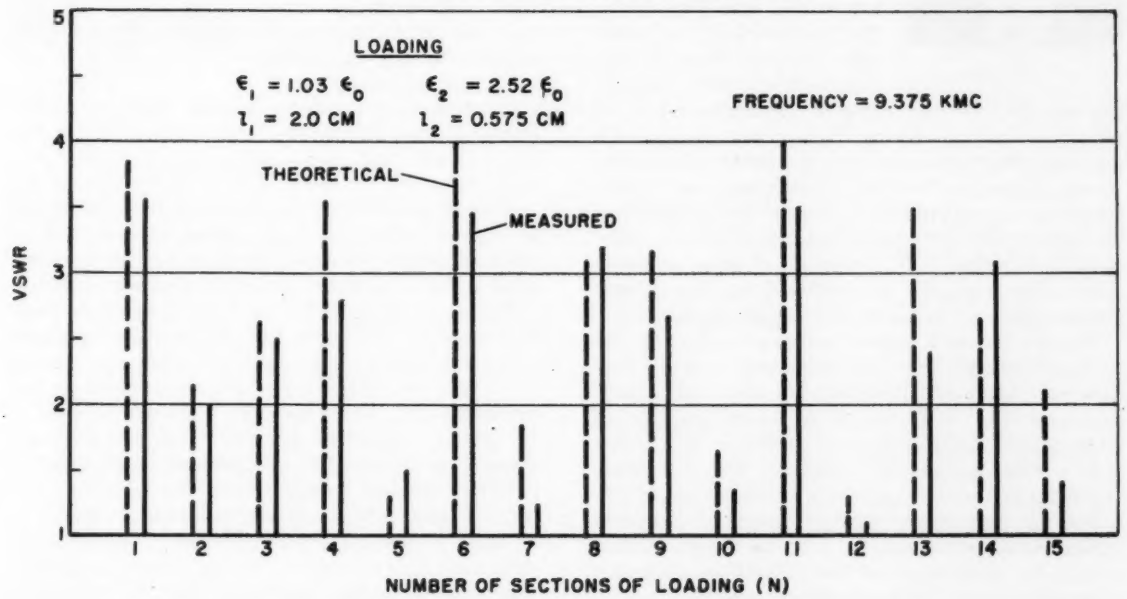

FIG. 14. VSWR VS. NUMBER OF SECTIONS OF LOADING (l_2=0.575 cm)

The results of measurements of β_{TE} for different loading and frequency are compared with theoretical values in Table I, $\Delta\theta$ being the difference in phase between the empty and loaded guide. The theoretical values were determined from $\Delta\theta = (\beta_{TE} - \beta_0)L$, where L is the length of the loaded guide and β_0 is the propagation constant of the empty guide. All values checked within one per cent.

The variation of VSWR with frequency is shown in Figs. 11 and 12; the variation of VSWR with the number of sections of loading (N) is shown in Figs. 13 and 14. The results of laboratory measurements are plotted for comparison. As N grew larger, the accuracy with which Eq. 17 could be evaluated decreased. Evaluating $\cot N\Gamma$ accurately for long sections became difficult. For example, an error in Γ of, say, 0.1 degrees yielded an error of 5 degrees with 50 sections of loading. If this occurred near zero degrees where the cotangent is changing rapidly, a large error would occur in the final expression for ρ.

(Continued on page 32)

PROCESS DESIGN OF FIXED-BED CATION-EXCHANGE UNITS

M. M. DAVID

Associate Professor of Chemical Engineering

R. F. PEAK

*Graduate Student in Chemical Engineering**

M. M. David

Ion-exchange methods have been used in water treatment for over fifty years. However, within the past two decades following upon the development of resinous ion-exchange materials having controllable physical and chemical properties, ion exchange has burgeoned into importance in a wide variety of uses. Ion exchange today is used not only for water softening but also for the complete demineralization of water for use in laboratories, power plants, and manufacturing processes, the treatment of aqueous wastes, recovery of valuable constituents from dilute solutions, sugar refining, uranium ore processing, biochemical and pharmaceutical manufacture, rare-earths production, and a multitude of other purposes —including even the treatment of stomach ulcers. Potentialities for future uses are most impressive.

Despite the widespread industrial usage of ion exchange, design and cost-estimating methods and data have not been adequately compiled and organized, and it is often difficult to locate this type of information. Accordingly, the intent of this paper is to present introductory material, design methods and data, and sources of such methods and data sufficient for preliminary process design of fixed-bed cation-exchange units. A process design should specify the dimensions of the bed of ion-exchange material, the operating conditions, and the costs of the equipment and operation. The design of the mechanical details of the equipment will not be considered; this topic has received adequate coverage elsewhere.[1,2,3,4] The design methods and data to be presented are for fixed-bed, ion-exchange systems, and do not pertain to newly developed ion-exchange methods such as moving-bed units, ion-exchange membranes, and ion-exclusion systems. These all have considerable promise for future applications, but at present the overwhelming majority of industrial ion-exchange systems employ fixed-bed operation. Discussion will be primarily limited to systems employing resinous exchangers, which are virtually the only type of exchange material used for applications other than water-softening. Most of the discussion and methods following will be concerned with cation-exchange units, but the same techniques will be largely applicable to anion-exchange units also. Hence, a small amount of data for anion-exchange units will be included.

R. F. Peak

FIXED-BED OPERATION

The usual fixed-bed ion-exchange unit consists of a vertical cylindrical tank containing the bed of resin supported on a porous plate or (more generally) a layer of gravel or other granular material. A free space of from 50 to 100 per cent of the resin bed height is left above the bed, and arrangements are provided for collecting and distributing liquids above and below the resin bed. In addition to the bed unit itself, tanks must be available for mixing or storing regenerant solution, and the necessary connecting piping and controls must be provided.

Before process design of the ion-exchange unit can be attempted, sufficient information must be at hand to define the problem, design methods and data must be available to size the unit and stipulate operating conditions, and cost data are needed to determine the fixed charges and operating costs. Each of these topics is considered in a following section. In preparing the process design, consideration must be given to the operating cycle used with fixed-bed ion-exchange units. Fixed-bed ion-exchange units operate on a cycle involving a number of basic steps, which, in the sequence normally used, are as follows:

1) ***Exhaustion.*** The influent solution, containing ions to be removed by the bed, is passed through the bed until these ions begin to appear in the effluent at an undesirably high level. At this point, termed the "breakthrough point," flow of liquid through the

* Now with the Cascade Cartridge Company, Lewiston, Idaho.

bed is halted. During exhaustion either upflow or downflow may be used, but the latter is the more common.

2) ***Backwash.*** Following exhaustion, water is passed upward through the bed at a rate sufficient to expand the bed by 50 to 100 per cent. This process cleans the bed of suspended solids. When backwashing is stopped, the bed settles in a manner that tends to classify the exchange material, and this in turn minimizes channeling through the bed in the remainder of the cycle.

3) ***Regeneration.*** A concentrated solution of the ion present on the bed before exhaustion is next passed through the bed. Ions taken up by the bed during exhaustion are thereby removed from the bed, which is returned to a fresh condition. The ions removed from the exhaustion solution are concentrated in the regenerant solution during this step.

4) ***Rinse.*** The regenerant solution remaining in the voids of the bed is flushed out by water or other liquid. The rinse liquid is sometimes purified before use to minimize loss of exchange capacity during exhaustion.

The washing steps are occasionally reversed in order, and many special treatment cycles and combinations of the above basic steps have been devised for special situations.[1,2,3] Whatever the cycle used, the process design should attempt to establish operating conditions in the various steps and to specify a bed size (or sizes) such that the over-all cost of the ion-exchange process is a minimum. Considerations involved in striving for this minimum cost are discussed subsequently.

REQUIRED DATA

Prior to the actual design of an ion-exchange unit, the following data must be compiled:[2]

1. An accurate analysis and description of the solution to be treated, and the ranges of variation to be encountered in these. Data on temperatures, viscosities, and densities should be included.
2. The volume of solution to be treated per unit time, including maximum and minimum rates.
3. Effluent composition required.
4. Regenerant chemicals and labor available.
5. Information on whether intermittent or continuous operation is desired, and the availability of temporary storage for smoothing fluctuations in flow rate of solution to be treated.
6. Information on available water pressure for washing and rinsing.
7. The physical and chemical characteristics of the exchange material to be used. (If information of this type pertaining to the problem at hand is not available, experimental studies may be needed to obtain it.)

DESIGN METHODS

The design methods used for fixed-bed ion-exchange units may be somewhat arbitrarily classified into two types: empirical and theoretical. The former are approximate design methods using only a limited amount of experimental data or based upon operating conditions found satisfactory in similar units. Theoretical methods employ a mathematical model, describing the fundamental processes occurring in the bed, to predict the performance of a unit. Some experimental data are needed for theoretical methods.

Empirical Methods

Standard Operating Conditions. The manufacturers of ion-exchange materials furnish considerable information and data on the properties and operating characteristics of their exchange materials, including suggested ranges of operating conditions.* These suggested operating conditions are based primarily upon water-treating data and are intended primarily for that use, as are the performance curves often accompanying the suggested operating conditions. Typical suggested conditions are the following:

Exchange medium	high-capacity polystyrene resin
Minimum bed depth	30 inches
Exhaustion flow rate	2-5 gpm per cu ft of resin 8-20 gpm per sq ft of bed cross section
Quantity of regenerant and resulting bed capacity	15 lb NaCl per cu ft—30 kilograins of $CaCO_3$ capacity per cu ft 6 lb H_2SO_4 per cu ft—17 kilograins of $CaCO_3$ per cu ft capacity
Regenerant concentration	NaCl—10 per cent H_2SO_4—variable, depending on cations present
Regenerant flow rate	1 gpm per cu ft of resin
Backwash conditions	8 gpm per sq ft of bed cross section, for 2-3 min
Rinsing conditions	0.5-1.0 gpm per cu ft of bed; 40-100 gal per cu ft

The exhaustion flow rate determines the bed size, and the remaining items, the operating conditions.

Use of standard operating conditions for design purposes requires no advance experimental work and provides the most rapid design method. However, no advance information is then available on leakage† and resin capacity. It is unlikely that use of standard operating conditions will result in the optimum design, and it is very possible that serious over- or

* See list of ion-exchange resin manufacturers at end of article.

† Leakage is the term used to describe the presence of cations other than the regenerant ion in the exhaustion effluent.

under-design and extra-heavy operating costs will occur for treatment of solutions quite different from those encountered in water-treating. To some extent, these shortcomings may be reduced by modification of operating conditions, once the unit is in operation.

Mindick's Method. Equations have been presented by Mindick[5] for using laboratory experimental data to design fixed-bed ion-exchange units. Use of these equations requires preselection of the operating conditions to be evaluated. However, the method is of value in enabling a known-to-be-operable unit to be designed on the basis of a small amount of experimental data, and it includes the effects of all ions present in the exhaustion solution and provides information on the working capacity of the resin and the leakage to be expected. The equations do not, per se, determine maximum allowable flow rates or optimum operating conditions.

To use the equations, a small laboratory bed must be operated through several cycles until steady conditions are obtained. (A minimum of two cycles could probably be used with reduced accuracy.) The following data are then procured: amounts of each ion in the exhaustion solution leaking through the bed and remaining on the bed to the breakthrough point; and the amount of each ion eluted from the bed during regeneration. These data are used in the following equation:

$$Q = \frac{Q_s}{(r_a/x_a)+(r_b/x_b)+(r_c/x_c)+\ldots.},$$

where

Q = operating capacity of resin,
$Q_s = (q_s)_a+(q_s)_b+(q_s)_c+\ldots.$,
r_a = ratio of ion A to the total exchangeable ions in the entering exhaustion solution,
$x_a = q_a/(q_s)_a$ = fraction of A on the bed at breakthrough which is eluted during regeneration,
$(q_s)_a$ = amount of ion A on the bed at breakthrough,
q_a = amount of A eluted from the bed during regeneration.

These equations are based primarily upon material balances, and include the assumptions that the column is operated with small leakage and that the presence of the regenerant ion in the exhaustion solution can be ignored for calculational purposes. The original article presents methods for correcting the calculations when large leakages exist.

Direct Scale-up. If large amounts of experimental data are available, the optimum design indicated by these laboratory data can be directly scaled-up to industrial size. Examples of this method are given in References 6 and 7. Usually, laboratory data indicate somewhat higher bed capacities and smaller leakages than are found in large units.[1] However, in systems with favorable equilibria, such scale-ups will be on the safe side, since the higher linear flow velocities used in large beds result in more rapid exchange than is found at the same volumetric flow rates in short laboratory units.[6]

Theoretical Methods

The Breakthrough-Curve Equation. A mathematical expression relating the composition of the effluent from a fixed bed with the influent composition, the volume of effluent, the flow rate, the bed size, the initial condition of the bed, and the resin characteristics is termed a breakthrough-curve equation. The utility of such an equation is obvious. With only a small amount of experimental work to evaluate the constants in the equation, the predicted performances of ion-exchange units can be computed over a wide range of operating conditions, and the optimum process design can be determined. To obtain the breakthrough-curve equation, a material balance on a differential length of the bed is combined with an equation for the rate of ion exchange and an equation relating the equilibrium compositions in the solution and on the resin. The resulting partial differential equation may usually be integrated by numerical or analytical means, using boundary limits set by the initial bed composition and the influent composition. The rate and equilibrium equations used largely determine the final form of the breakthrough equation.

Factors Affecting the Breakthrough Equation. The type of equilibrium existing between non-complexing cations in solution and on the resin immersed in the solution is chiefly influenced by the relative valences of the exchanging ions and the concentration of the solution. When ions of equal valence are exchanging, the equilibrium is often linear; i.e., the ratios of the ions on the resin are about the same as their ratios in the solution;* and the equilibrium is not greatly affected by the total solution concentration.[8,10,11] For exchange of ions with different valences, in dilute solutions the ion with the larger valence is usually very preferentially taken up by the resin; i.e., the equilibrium is strongly in favor of higher valence ions.[8,10,12,13,14,15] As the solution strength increases, the favorability of the equilibrium for the higher valence ion decreases, and at high concentrations the equilibrium approaches linearity and may even reverse itself so that the lower valence

* When the ions involved have very different hydrated radii, the ion with the smaller hydrated radius is preferentially "adsorbed" by the resin.[8,9] Ions which form complexes in solution are also less strongly "adsorbed."

ion is preferentially taken up.[12,14] Were this effect of concentration on equilibrium not present, regeneration of polyvalent ions with the commonly used regenerants (NaCl and H_2SO_4) would be an extremely inefficient process. The concentration ranges at which the various types of equilibrium prevail in non-equivalent exchange depend upon the particular ions involved. Complete, or fairly complete, data on this effect are available for a few systems: Cu^{++}-Na^{+}, Ca^{++}-Na^{+}, Mg^{++}-K^{+}, and Fe^{+++}-H^{+} (References 12, 14,15,13 respectively), and a comprehensive listing of other more limited data has been compiled.[16]

The rate of the ion-exchange reaction may be governed by one or more of the several steps which occur in the process. An ion leaving the solution must diffuse through the liquid surrounding the resin particle, and must then diffuse through the pores of the particle till it reaches an available exchange site. Here the actual chemical reaction of the exchange takes place, and the replaced ion must then diffuse out through the pores and through the surrounding liquid film around the resin particle. Diffusion of one of the ions, either through the liquid film, or through the pores, or through both, determines the over-all reaction rate.[17] Which one of the diffusional steps is actually controlling depends primarily upon the velocity of the solution relative to the resin bed (which affects the resistance to diffusion offered by the liquid film) and the concentration of the external solution. At flow rates ordinarily found in ion-exchange units during exhaustion, diffusion through the liquid film is the rate-controlling step in dilute solutions,[17,18,19,20] and diffusion within the pores becomes rate-controlling at higher concentrations. At intermediate concentrations, both diffusional resistances are the same order of magnitude.[9,11,17,21]

Numerical specification of the concentration ranges within which the various diffusional steps are controlling depends again on the specific system. For uni-univalent exchange it has been found that internal diffusion becomes important at total-solution molarities above 0.003, and controlling at total-solution molarities above 0.1 M.[9,17] Other studies indicate that, for poly-univalent exchange, liquid-film diffusion may control up to much higher solution strengths,[18] in fact as high as 0.5 M in one instance.[20] Other relative data may be found in References 11 and 21. At present very few rate data are available for high solution-concentration, low flow-rate situations such as are encountered in regeneration.

Breakthrough Equations Available. Solutions to the partial differential form of the breakthrough equation are presently limited to systems involving only two exchanging ions; i.e., systems where a single ionic species in solution is replacing a single ionic species on the resin. This limitation places a severe restriction on the use of theoretical methods for practical design purposes, since many of the solutions to be treated by ion exchange contain several ions which will be retained on the bed.* The available evidence[6,22] indicates that breakthrough equations based on only two ionic species exchanging cannot be used to predict the breakthrough curve for one of these species if a third ionic species is present. Other limiting assumptions contained in available solutions are constant flow rate, inlet composition and initial bed composition, uniform conditions across the bed cross section, and no diffusion in the direction of flow.

The types of systems for which integrated breakthrough equations are available (systems with two ionic species) are indicated in Table I. Though the attempt was made to include all the existing types of solutions, in view of the very large number of articles on ion-exchange which have appeared in recent years it is quite possible that some of the available breakthrough-curve equations have been omitted. No attempt has been made to list all the articles containing derivations of these or very similar solutions.

TABLE I
AVAILABLE BREAKTHROUGH-CURVE EQUATIONS

SYSTEM	REF. NO.	TYPE OF SOLUTION
Very favorable equilibrium, liquid film controlling	18	Analytical
Very favorable equilibrium, internal diffusion controlling	23	Analytical
Linear equilibrium, liquid film controlling	24	Analytical*
Linear equilibrium, internal diffusion controlling	25	Numerical
Linear equilibrium, both internal and external diffusion important	25	Numerical
	11,26	Analytical*
Intermediate equilibria, liquid film controlling	27,28	Analytical*
Intermediate equilibria, internal diffusion controlling	23	Analytical

* Numerical solutions for these cases are also available (e.g., Reference 29).

Examples of the use of breakthrough equations for design purposes may be found in References 18 and 19.

Other Theoretical Approaches. Both the Htu (height of a theoretical unit) and the HETP (height of a theoretical plate) concepts have been applied to fixed-bed ion-exchange data (e.g., References 4 and 30, respectively). Neither of these approaches appears especially useful for fixed-bed design purposes, though the latter might be useful for operations

* However, if two of the ions in the exhaustion feed have the same valence and are similar in size, they may be treated as a single species when replacing an ion of lower valence on the resin.[6,19]

which are essentially chromatographic in nature and can handle systems containing several ionic species, if the equilibrium relationships are fairly simple.

COSTS

The total costs for operating a fixed-bed ion-exchange system can be grouped into the two usual categories of fixed costs and operating costs. The former are those primarily dependent upon the initial purchase price of the system and the latter vary almost directly with the extent of use of the system. As in most process design, larger units, more instrumentation, and other factors which increase the fixed costs result in decreased operating costs. The optimum process design is usually the one which results in a minimum total cost of operation.

Fixed Costs

The most important fixed (capital) costs for ion-exchange equipment are depreciation, maintenance, interest on investment, taxes, and insurance. Generally these costs are expressed as a percentage of the initial installed costs. Considerable purchase- and installation-cost data for fixed-bed ion-exchange systems are now available in the literature[31,32,33,34] and will not be included here because of the space requirements for adequate presentation.

Depreciation. Depreciation rates can vary widely, depending upon company policy and bookkeeping procedures. Many companies will amortize a process in a much shorter period than the process will actually be operative, and this procedure is warranted if there is danger of obsolescence of the process. Another procedure, used for income tax purposes, depreciates the equipment over the expected useful life. The Bureau of Internal Revenue's table of estimated useful life of equipment used in the process industries[35] indicates that tanks and equipment used in sodium cycle units (NaCl regenerant) should have a useful life of 20 years, and in acid cycle units, 15 years. These figures allow approximately 5 and 7 per cent per year straight-line depreciation on the respective types of equipment. Although depreciation of the resin itself is minimized by regular addition of replacement resin* these percentage figures may be applied to the total initial investment, to provide a slightly faster write-off. Amortization over a 10-year period has also been suggested for ion-exchange units.[36]

Repair and Maintenance. These costs for chemical process equipment are computed at 2 to 10 per cent of the installed cost, depending upon the complexity of the equipment.[37,38] Ion-exchange equipment is relatively simple, with few moving parts; hence a figure of 5 per cent for repair and maintenance would appear reasonable.[38]

* See subsequent discussion on operating costs.

Interest on Investment. The charge for interest on investment, as with depreciation, depends upon company policy. A figure of 4 per cent per year based on installed cost is often used,[37,38,39] though this value may be slightly low at the present time.

Taxes and Insurance. Property taxes vary considerably throughout the United States. The rate may be from 1 to 6 per cent of the assessed value and the assessed value may range from 25 to 100 per cent of the replacement value of the equipment. A reasonable average between these combinations of extremes is often taken as 2 per cent of the installed cost of the equipment.[37,38] This figure is for the property tax only. The cost of insurance for fire or other type of property loss is small, and 1 per cent of the equipment cost is commonly used for estimation purposes.[37,38]

TABLE II
FIXED COSTS FOR ION-EXCHANGE UNITS

ITEM	FIXED OPERATING COST (% per year of initial installed cost)	
	Sodium Cycle	*Acid Cycle*
Depreciation	5	7
Repairs and Maintenance	5	5
Interest on Investment	4	4
Property Taxes	2	2
Insurance	1	1
Total	17	19

Mindler and Paulson[34] suggest a figure of 15 per cent of installed cost for yearly fixed charges. Monet[32,33] uses 15 per cent per year for depreciation and maintenance only. Fixed costs for ion-exchange units are summarized in Table II.

Operating Costs

The major operating charges of an ion-exchange unit usually are for regenerant chemicals, water, and operating labor. Pumping costs can also be important in systems having large pressure drops, instrument maintenance may be a major item in complex automatically-controlled systems, and resin replacement cost can be high for treating solutions having constituents which are destructive to the resin.

Regenerant Chemicals. This cost generally accounts for 20 to 50 per cent of the total operating costs for an ion-exchange system.[32,33] For water-treating units, 30 per cent of total costs is common, but this figure can be considerably higher for special recovery and chemical treatment units. The cost of regenerant chemicals is directly proportional to the number of chemical equivalents of ions removed from the exhausting solution and to the efficiency of regenerant usage. The former is fairly rigidly established by the requirements of the process, but methods of improving efficiency of regenerant usage should be

examined in seeking the optimum process design.

Less complete regeneration of a bed results in increased efficiency of regenerant usage but also necessitates a larger bed (with higher fixed costs) or more frequent regenerations (with higher labor costs). Relaxing leakage requirements slightly, when such requirements are unusually stringent, can reduce regenerant requirements greatly (or, alternatively, reduce the bed-size needed). The effects of type of regenerant, regenerant strength, and regeneration flow rate upon the efficiency of regeneration should be studied, if possible. However, this usually requires experimental work. Reuse of the less spent portions of the regenerant in a semi-countercurrent fashion is another possible method for reducing regenerant costs. As a general rule, the efficiency of regenerant usage in fixed-bed units is approximately 50 per cent, and from 1.5 to 2.5 times the theoretical amount of regenerant is needed.[32] The costs for typical regenerants are given in Table III.

TABLE III
COSTS OF REGENERANT CHEMICALS

REGENERANT	COST[40] (F.O.B.)	COST PER LB-EQUIV.
NaCl	\$ 0.98/100 lb	\$ 0.57
H_2SO_4	\$22.50/ton 66° Be	\$ 0.57
HCl	\$ 1.40/100 lb 18° Be	\$ 1.70
Na_2CO_3	\$ 1.60/100 lb	\$ 0.85
NaOH	\$ 5.40/100 lb (flake, 76% Na_2O)	\$ 1.67
NH_3	\$82.50/ton (anhydrous)	\$ 0.70

Rinse and Backwashing Water Requirements. Published values[32,41,42] and manufacturers' data indicate that from 40 to 150 gal of water per cubic foot per cycle are needed for rinsing and backwashing. A figure of 50 gal per cubic foot per cycle is typical for sodium-cycle operation, and larger amounts are used for acid-cycle operation. Water for backwashing represents only a small fraction of the total water requirements. Industrial water costs are frequently of the order of \$0.14 per 1000 gal for municipally supplied water,[32] but the cost is considerably lower for well water or water from other natural sources. For complete demineralization of water, treated effluent from the ion-exchange system is usually used as rinse water, and this may cost \$0.20 to \$0.30 per 1000 gal above the cost of raw water.[33] Based on the above figures, the cost of rinse and backwash water will often be in the range of \$0.005 to \$0.05 per cubic foot of bed for each cycle.

Labor. Costs of labor for fixed-bed ion-exchange units depend upon the extent to which automatic controls are used. If automatic controls are not used, the operator must devote full time to the process during backwash and regeneration, half-time during the rinse, and approximately 15 minutes during the exhaustion step.[33] This frequently amounts to about 2 hours per cycle,[32] though the exact amount of time depends upon the particular process and is determined during the calculation of the process design. If automatic controls are used, labor costs can be reduced to a minimum and the operator would be needed only for filling the regenerant chemical tank, initiating the regeneration cycle, and checking the operation of the system from time to time. A comparison between savings in labor costs and the additional costs of automatic controls* determines the best procedure for a given system. As mentioned earlier, extensive use of automatic controls increases the costs of instrument maintenance. Labor costs must also be balanced against bed costs in determining the optimum operating cycle. Smaller beds (for the same process) require more of the operator's time but have smaller fixed charges. The cost of labor for operation of ion-exchange units will probably approach \$2.50-\$3.00 per hour, including 25 per cent of the basic hourly rate for supervision and payroll overhead costs (insurance, social security, pensions, etc.).[38]

Power for Pumping. The cost of pumping may be of interest for ion-exchange processes in which the streams to be treated are not under sufficient pressure to force them through the unit, a situation of particular concern with thick, viscous liquids. In such cases the bed depth should be chosen so that the maximum pressure remains within the normal equipment limitation of 100 psi, and so that the pressure drop through the bed will not place undue mechanical stress on the resin or result in tight packing of the bed. The power requirements for pumping are directly proportional to the flow rate and pressure drop through the bed. Pressure drops through the bed may be determined from data furnished by the resin manufacturers or by standard techniques for flow through packed beds.[43,44] The theoretical power requirements should be approximately doubled to allow for pump, drive, and motor efficiencies. A power cost of \$0.01 per kilowatthour will be on the safe side.

Resin Replacement. This cost is usually a small portion of the over-all operating cost of an ion-exchange unit. The attrition rate of resin in ordinary service is generally 3 per cent per 500 cycles or less. If the attrition rate is taken as 1 per cent per 100 cycles, replacement resin costs, with daily regeneration, are about 3 per cent per year. The figure of 5 per cent per year for resin replacement has also been suggested.[32] Solutions which are especially destructive to the resin or which tend to reduce the resin capacity may result in higher resin replacement costs.

* See Reference 31 for cost data on automatic controls.

REFERENCES

1. Nachod, F. C., and Schubert, Jack (ed.) *Ion Exchange Technology*, Academic Press Inc., New York, 1956.
2. Nachod, F. C. (ed.), *Ion Exchange—Theory and Application*, Academic Press, New York, 1949.
3. Kunin, Robert, and Meyers, R. J., *Ion Exchange Resins*, John Wiley & Sons, New York, 1950.
4. Hiester, N. K., and Phillips, R. C., *Chem. Engg.* **61**, No. 10, 161 (1954).
5. Mindick, Morris, *Ind. Eng. Chem.*, **47**, 96 (1955).
6. David, M. M., D. Eng. Thesis, Yale Univ., 1950.
7. McGarvey, F. X., Tenhoor, R. E., and Nevers, R. P., *Ind. Eng. Chem.*, **44**, 534 (1952).
8. Boyd, G. E., Schubert, Jack, and Adamson, A. W., *J. Am. Chem. Soc.*, **69**, 2818 (1947).
9. Bieber, H., Steidler, F. E., and Selke, W. A., *Chem. Engg. Progr. Symposium Ser. No. 14*, **50**, 17 (1954).
10. Bauman, W. C., and Eichorn, J., *J. Am. Chem. Soc.*, **69**, 2830 (1947).
11. Gilliland, E. R., and Baddour, R. F., *Ind. Eng. Chem.*, **45**, 330 (1953).
12. Subba Rao, H. C., and David, M. M., *A.I.Ch.E. Jour.*, 3 (June, 1957).
13. Vasishth, R. C., and David, M. M., "Equilibrium in the System Fe^{+++}-H^{+}-Dowex 50," presented at Am. Chem. Soc. Northwest Regional Meeting, June, 1957.
14. Bauman, W. C., Skidmore, J. R., and Osmun, R. H., *Ind. Eng. Chem.*, **40**, 1350 (1948).
15. Gregor, H. P., Abolafia, O. R., and Gottlieb, M. H., *J. Phys. Chem.*, **58**, 984 (1954).
16. Subba Rao, H. C., M. S., Thesis, Univ. of Wash., 1956.
17. Boyd, G. E., Adamson, A. W., and Meyers, L. S., Jr., *J. Am. Chem. Soc.*, **69**, 2836 (1947).
18. Selke, W. A., and Bliss, R. H., *Chem. Eng. Prog.*, **46**, 509 (1950).
19. Hagerty, P. F., and Bliss, R. H., *Ind. Eng. Chem.*, **45**, 1253 (1953).
20. Mar, Brian, and David, M. M., *A.I.Ch.E., Jour.*, 2, 381 (1956).
21. Sujata, A. D., Banchero, J. T., and White, R. R., *Ind. Eng. Chem.*, **47**, 2193 (1955).
22. Bitar, L. S., B.S. Thesis, Univ. of Wash., 1956.
23. Vermeulen, T., *Ind. Eng. Chem.*, **45**, 1664 (1953).
24. Thomas, H. C., *Ann. N.Y. Acad. Sci.*, **49**, 161 (1948).
25. Rosen, J. B., "General Numerical Solution for Solid Diffusion in Fixed Beds," A.I.Ch.E. Meeting, San Francisco, Sept., 1953.
26. Eagleton, L. C., Ph.D. Thesis, Yale Univ., 1951.
27. Hiester, N. K., and Vermeulen, T., *Chem. Eng. Prog.*, **48**, 505 (1952).
28. Vermeulen, T., and Hiester, N. K., *J. Chem. Phys.*, **22**, 96 (1954).
29. Opler, A., and Hiester, N. K., "Tables for Predicting the Performance of Fixed-Bed Ion Exchange," Stanford Res. Inst., 1954.
30. Said, A. S., *A. I. Ch. E. Jour.*, **2**, 477 (1956).
31. Peak, R. F., and David, M. M., *Chem. Eng. Progr.*, **53**, 37 (1957).
32. Monet, G. P., in Reference 1.
33. Monet, G. P., *Chem. Eng.*, **57**, No. 3, 106 (1950).
34. Mindler, A., and Paulson, C. E., *Chem. Week*, **75**, No. 5, 45 (Dec., 18, 1954).
35. *Bulletin "F,"* U.S. Bur. Inter. Rev., Washington, D.C.
36. Kahler, F. H., and Reents, A. C., *Chem. Eng.*, **61**, No. 1, 206 (1957).
37. Tyler, C., *Chemical Engineering Economics*, 2nd Ed., McGraw-Hill Book Co., Inc., New York, 1948.
38. Aries, R. S., and Newton, R. D., *Chemical Engineering Cost Estimation*, McGraw-Hill Book Co., Inc., New York, 1955.
39. Zimmerman, O. T., and Lavine, I., *Chemical Engineering Costs*, Industrial Research Service, Dover, New Hampshire, 1950.
40. *Chem. and Eng. News*, March 25, 1957.
41. Wirth, L., Jr., *Power*, **93**, No. 11, 96 (Nov., 1949).
42. Maudrau, J. E., *Ind. Eng. Chem.*, **43**, 615 (1951).
43. Ergun, S., *Chem. Eng. Progr.*, **48**, 89 (1952).
44. Perry, J. H. (ed.), *Chemical Engineers' Handbook*, 3d Ed., Sec. 5, McGraw-Hill Book Co., New York, 1950.

Ion-Exchange Resin Manufacturers*

Chemical Process Co., 901 Spring St., Redwood City, Calif.
Dow Chemical Co., Midland, Mich. (Commercial quantities of resin manufactured by Dow are sold and serviced by National Aluminate Corp., 6216 W. 66th Place, Chicago.
Permutit Co., 330 W. 42nd St., New York.
Rohm and Haas Co., Washington Square, Philadelphia, Pa.

* A list of ion-exchange equipment manufacturers and suppliers may be found in Reference 31.

THE GRADUATE MEETS INDUSTRY

(Continued from page 2)

Time was when any commencement orator could impressively point out the glorious "new world" on whose firm threshold the graduate was poised. Today, the graduating engineer, who is peculiarly equipped to conduct stability tests, must watch his step. In addition to the professional questions confronting him personally, he is handed some of the toughest problems the world has ever known, and is expected to come up with at least part of the answers. As one speaker put it, "he faces a triple threat: annihilating war, vanishing natural resources, and a surging world population that will, unless it is somehow checked, multiply 2½ times in the next hundred years. Solution of these problems cannot be long delayed. Of course, science can help to find some of the answers. The real basis for man's survival and well-being, lies, however, in a new culture. Somehow men will have to learn how to live in harmony and mutual understanding.... The real objective can best be reached through developing... a liberal, homogeneous blend of knowledge, rationality, creativity, objectivity, mutuality, and spirituality."[18] That is a tremendous challenge. One heartening feature is that it was issued by the vice president of the laboratories of one of our largest industries.

REFERENCES

1. Armore, S. J., and Armsby, H. H., "Engineering Enrollments and Degrees," *Jour. Engg. Ed.*, Mar., 1957.
2. Massue, H., "L'Orientation des Ingeniurs," *L'Ingenieur*, Spring, 1956.
3. "National Conference on Scientific Engineering, and Technical Manpower," Sept., 1956.
4. "SRA Employee Inventory," Science Research Associates, Industrial Relations Center, Uni. of Chicago, 1952, *via* Moore, D., and Renck, R., "The Professional Employee in Industry," *Jour. of Business*, Jan. 1955.
5. Rusch, H. L., and Goecke, J. R., "What Engineers Expect from Industry," *Chem. & Engg. Prog.*, Jan., 1957.
6. Shepard, H. A., "Engineers as Marginal Men," *Jour. Engg. Ed.*, Mar., 1957.
7. "Ethics in a Changing Era," Report of the Committee on Ethics, *Ibid*, Oct., 1956.
8. "Teamwork Takes Terpenes' Measure," *Chem. Week*, June 1, 1957.
9. Nelles, M., "Deliberate Creativeness in Science and Engineering," *Chem. Bull.*, Feb., 1953.
10. "Size up the Productive Researcher," *Chem. Week*, May 25, 1957.
11. Harvard Business School EAR 30R, 1949.
12. Lehman, H. C., *Age and Achievement*, Princeton Uni. Press, New York, 1953.
13. Schmooker, J., *Jour. Pat. Off. Soc.*, April, 1956.
14. Shepard, H. A., Creativity in R/D Teams," *Res. and Engg.*, Oct., 1956.
15. Dubridge, L. A., "Scientists and Engineers: Quantity Plus Quality," *Science*, Aug. 17, 1956.
16. Stevenson, E. P., "The Scientist-Engineer," *Jour. Engg. Ed.*, Oct., 1956.
17. Adler, R. B., "Science and Engineering Education," *Ibid.*
18. Green, E. I., "Science and Liberal Education," *Ibid.*, Mar., 1957.

PUBLICATIONS AND GRADUATE THESES

College of Engineering 1956-1957

(EES: Engineering Experiment Station Assistant)

AERONAUTICAL ENGINEERING

Dill, Ellis H., "The Vibrations of Plates and Plate Systems," Ph.D. Thesis, Dept. of Civil Engineering, University of California, 1956.

Graf, D. A. "Experimental Investigation of Laminar Heat Transfer from a Uniformly Heated Flat Plate at Mach 2.5" **(with R. E. Street),** *The Trend in Engineering,* Vol. 8, No. 1 (Jan. 1956).

Levinsky, E. S., "Approximate Laminar Skin Friction in Compressible Flows with Favorable Pressure Gradients," *The Trend in Engineering,* Vol. 9, No. 2 (April, 1957).

Martin, H. C., "Truss Analysis by stiffness considerations," *Proceed.,* ASCE, Paper 1070 *(Engg. Mech. Div.),* 1956.

Street, R. E., "Experimental Investigation of Laminar Heat Transfer from a Uniformly Heated Flat Plate at Mach 2.5" **(with D. A. Graf),** *The Trend in Engineering,* Vol. 8, No. 1 (Jan. 1956).

————, *Problem of Slip Flow in Aerodynamics,* NACA RM 57A30, Mar. 4, 1957.

M.S. in Aeronautical Engineering

AOKI, YOSHI, Temperature Stabilization for Intermittent Pressurized Supersonic Wind Tunnels (1956).

HITCH, H., The Computation of Normal Modes for a Complete Aeroplane (1956).

II, M., Analysis of Nonlinear Longitudinal Motion of a Missile in Supersonic Flight (1957).

LEVINSKY, E. S., Approximate Compressible Laminar Skin Friction with Favorable Pressure Gradients (1956).

LOMAX, T. L., Horizontal Tail Maneuver Load Studies 1956).

MARHEFKA, J. M., Torsional Rigidity of an Aerosol Model Spar: Theory and Experiment (1956).

MODI, V. J., Deflection and Stiffness of Swept Plates Due to In-Plane Loading (1957). (EES)

NIELSEN, J. C., The Effect of High Supersonic Mach Numbers on Longitudinal Dynamic Stability Derivatives (1957).

RISDAL, R. E., The Effect of Compressibility on Downwash Behind a Sweptback Wing at Subsonic Speeds (1956).

SHERMAN, L. L., The Effect of Structural Damping on Vibration Mode Shapes and Frequencies (1956).

CHEMICAL ENGINEERING

Ahola, A., "Lignin VII: Distribution in Molecular Weight of Certain Lignin Sulfonates" **(with V. F. Felicetta and J. L. McCarthy),** *J. Am. Chem. Soc.,* **78,** 1899 (1956). (EES Reprint No. 102)

Babb, A. L., "Diffusion in the System Methanol-Benzene" **(with C. S. Caldwell),** *J. Phys. Chem.,* **59,** 1113 (1955).

————, "Diffusion in Ideal Binary Liquid Mixtures" **(with C. S. Caldwell),** *Ibid.,* **60,** 51 (1956).

————, "Self-Diffusion in Liquids: I. Concentration Dependence in Ideal and Non-Ideal Binary Solutions" **(with P. A. Johnson),** *Ibid.,* **60,** 14 (1956).

————, "Reactor Engineering" (book review), *Chem. and Engg. News,* **34,** 320 (1956).

————, "Diffusion of Nonelectrolytes" **(with P. A. Johnson),** *Chem. Rev.,* **56,** 387 (1956).

————, "A Mach-Zehnder Interferometer for Diffusion Measurements in Volatile Liquid Systems" **(with C. S. Caldwell, J. R Hall),** *Rev. Sci. Inst.,* Sept. 1957.

Bach, E., "Diffusion Cell Scanning Attachment for the Beckman Model DU Spectrophotometer" **(with V. F. Felicetta, J. L. McCarthy),** *Anal. Chem.* (in press).

Bengston, K. B., "Magnesium from Olivine *via* Chlorination: A Possibility," *The Trend in Engineering,* Vol. 8, No. 1 (Jan., 1956).

Caldwell, C. S., "Diffusion in the System Methanol-Benzene" **(with A. L. Babb),** *J. Phys. Chem.,* **59,** 1113 (1955).

————, "Diffusion in Ideal Binary Liquid Mixtures **(with A. L. Babb),** *Ibid.,* **60,** 51 (1956).

————, "A Mach-Zehnder Interferometer for Diffusion Measurements in Volatile Liquid Systems" **(with A. L. Babb, J. R. Hall),** *Rev. Sci. Inst.,* Sept. 1957.

David, M. M., "Ferric Ion Removal from Dilute Acidic Solutions by Fixed-Bed Cation Exchange" **(with B. W. Mar),** *AIChE Jour.,* **2,** 3 (Sept., 1956).

————, "Costs of Cation Exchange Equipment" **(with R. F. Peak),** *Chem. Engg. Prog.,* **53,** 1 (Jan. 1957), (Reprinted in *Combustion.*) (EES Reprint No. 111)

————, "Countercurrent Steam Stripping of CO_2 from Soda-Lye Solutions" **(with F. J. Young),** *The Trend in Engineering,* Vol. 9, No. 1 (Jan. 1957).

————, "Equilibrium in the System Cu^{++}—Na^{+}—Dowex 50" **(with H. C. Subba Rao),** *AIChE Jour.,* June, 1957.

————, "Process Design of Fixed-Bed Cation-Exchange Units" **(with R .F. Peak),** *The Trend in Engineering,* Vol. 9, No. 3 (July, 1957).

————, "Related Fields," a chapter in *Opportunities in Chemical Engineering,* Vocational Guidance Manuals, Inc., 1957.

Felicetta, V. F., "Lignin VII: Distribution in Molecular Weight of Certain Lignin Sulfonates" **(with A. Ahola, J. L. McCarthy),** *J. Am. Chem. Soc.,* **78,** 1899 (1956). (EES Reprint No. 102)

————, "Lignin VIII: Molecular Weights of Lignin Sulfonates During Delignification by Bisulfite-Sulfurous Acid Solutions" **(with E. Nokihara, M. J. Tuttle, J. L. McCarthy),** *J. Am. Chem. Soc.* (in press).

————, "Lignin IX: Molecular Weights of Lignin Sulfonates as Influenced by Certain Acidic Conditions" **(with J. L. McCarthy),** *J. Am. Chem. Soc.* (in press).

————, "Diffusion Cell Scanning Attachment for the Beckman Model DU Spectrophotometer" **(with E. Bach, J. L. McCarthy),** *Anal. Chem.* (in press).

Hall, J. R., "A Mach-Zehnder Interferometer for Diffusion Measurements in Volatile Liquid Systems" **(with A. L. Babb, C. S. Caldwell),** *Rev. Sci. Inst.,* Sept. 1957.

Johnson, P. A., "Self-Diffusion in Liquids: I. Concentration Dependence in Ideal and Non-Ideal Binary Solutions" **(with A. L. Babb),** *J. Phys. Chem.,* **60,** 14 (1956).

————, "Diffusion of Nonelectrolytes" **(with A. L. Babb),** *Chem. Rev.,* **56,** 387 (1956).

Mar, B. W., "Ferric Ion Removal from Dilute Acidic Solutions by Fixed-Bed Cation Exchange" **(with M. M. David),** *AIChE Jour.,* **2,** 3 (Sept., 1956).

McCarthy, J. L., "Lignin VII: Distribution in Molecular Weight of Certain Lignin Sulfonates" **(with V. F. Felicetta, A. Ahola),** *J. Am. Chem. Soc.* **78,** 1899 (1956). (EES Reprint No. 102)

————, "Contributions of Chemical Engineering to Pulp and Paper Technology," *Chem. Engg. Prog.,* **53,** 162 (1957).

———, "Lignin VIII: Molecular Weights of Lignin Sulfonates During Delignification by Bisulfite-Sulfurous Acid Solutions" **(with E. Nokihara, M. J. Tuttle, V. F. Felicetta),** *J. Am. Chem. Soc.* (in press).

———, "Lignin IX: Molecular Weights of Lignin Sulfonates as Influenced by Certain Acidic Conditions" **(with V. F. Felicetta),** *J. Am. Chem. Soc.* (in press).

———, "Diffusion Cell Scanning Attachment for the Beckman Model DU Spectrophotometer" **(with E. Bach, V. F. Felicetta),** *Anal. Chem.* (in press).

Miller, A. P., Heat Transfer to Liquid-Solid Suspensions in Turbulent Flow in Pipes," **(with R. W. Moulton),** *The Trend in Engineering,* Vol. 8, No. 2 (April, 1956).

Moulton, R. W., "Heat Transfer to Liquid-Solid Suspensions in Turbulent Flow in Pipes" **(with A. P. Miller),** *The Trend in Engineering,* Vol. 8, No. 2 (April, 1956).

———, "Metallic Borides and Silicides by Fused Salt Electrolysis" **(with H. T. Fullam),** *AICHE Jour.* (to appear) Dec. 1957.

Nokihara, E., "Lignin VIII: Molecular Weights of Lignin Sulfonates During Delignification by Bisulfite-Sulfurous Acid Solutions" **(with M. J. Tuttle, V. F. Felicetta, J. L. McCarthy),** *J. Am. Chem. Soc.* (in press).

Peak, R. F., "Costs of Cation Exchange Equipment" **(with M. M. David),** *Chem. Engg. Prog.,* **53,** 1 (Jan., 1957), (Reprinted in *Combustion*). (EES Reprint No. 111)

———, "Process Design of Fixed-Bed Cation-Exchange Units" **(with M. M. David),** *The Trend in Engineering,* Vol. 9, No. 3 (July, 1957).

Subba Rao, H. C., "Equilibrium in the System Cu^{++}-Na^{+}-Dowex 50" **(with M. M. David),** *AICHE Jour.,* June, 1957.

Tuttle, M. J., "Lignin VIII: Molecular Weights of Lignin Sulfonates During Delignification by Bisulfite-Sulfurous Acid Solutions" **(with E. Nokihara, V. F. Felicetta, J. L. McCarthy),** *J. Am. Chem. Soc.* (in press).

Young, F. J., "Countercurrent Steam Stripping of CO_2 from Soda-Lye Solutions" **(with M. M. David),** *The Trend in Engineering,* Vol. 9, No. 1 (Jan., 1957).

Ph.D. in Chemical Engineering

ARORA, I. K., Rate-Controlling Mechanisms in the Corrosion of Single Crystals of Zinc in Aqueous Solutions (1956).

BENGSTON, K. B., Chlorination of Olivine Employing Fluidized Solids (1957).

FRANKLIN, F. C., Effect of Pressure on Catalytic Cracking (1957).

FULLAM, H. T., Electrolysis of Fused Salt Mixtures (1956).

GRANQUIST, D. P., The Oxidation of Hydrogenated Lignin from Douglas Fir Wood (1956).

HARDT, A. P., A Study of Mutual and Self Diffusion Coefficients in Non-Ideal Binary Liquid Mixtures (1957).

OLIN, B. E., Continuous Countercurrent Ion Exchange Resin Particle Settling Rates and Mass Transfer in Spinner Columns (1956). (EES)

SZEGO, G. C., Simultaneous Reaction and Distillation in a Catalyst-Packed Column (1956). (EES)

YASUI, G., Characteristics of Air Pockets in Fluidized Beds (1956).

M.S. in Chemical Engineering

BUTTON, E. F., Oxidative Cleavage of Lignin Sulfonates with Copper and Mercury Oxides (1956).

CHAMBERLAIN, H. V., Some Fundamental Concepts of Gas-Solid Heat Transfer in a Fluidized Bed (1956).

CHANG, Y-S., Effect of Cathodic Current Density on Corrosion Rate of Lead in Lead-Nitrate Solutions (1956).

COLVILLE, A. R., JR., Research and Development of Processes for Desalting Sea Water by Freezing (1956). (EES)

GLAZE, H. S., JR., Plate Efficiencies for the Steam Stripping of Carbon Dioxide from Sodium Carbonate-Bicarbonate Solutions (1957). (EES)

HIMMELBLAU, D. M., Kinetic Studies of Carbonation Reactions Using Radioactive Tracers (1956).

KOTZERKE, D. F., Vapor-Liquid Equilibria in the System Sodium Hydroxide-Sulfur Dioxide-Water (1956).

LUNG-MESTREZAT, M. P., Recovery of Heat and Process Chemicals from Spent Liquors of Sodium Base Sulfite Pulp Manufacture (1956).

MAR, B. W., Self Diffusion of Water in the Systems Acetone-Water and Methanol-Water (1956). (EES)

MARSHALL, N. J., The Effect of Light of Different Wavelengths on the Degradation of Clear Coatings (1956).

MOTWANI, G. C., A Study of Various Processes for Desalting Sea Water by Freezing (1956). (EES)

PARR, E. D., A Study of Turbulent Shear Flow in Noncircular Pipes (1956).

PERET, W. S., A Study of Ion-Exchange Equilibria of Sodium and Hydrogen Ions on Dowex-50 (1956).

ROMERO, J. B., Adsorption Kinetics in the Conversion of Carbon Dioxide to Methane (1957).

SUBBA RAO, H. C., Equilibrium in the System Cu^{++}-Na^{+}-Dowex 50 (1956).

WILDE, D. J., Aggregative Fluidization of a Solid with a Liquid (1956).

YANG, M., Cathodic Production of Hydrogen Peroxide (1956).

YEE, S., The Corrosion of Lead in Basic Lead (1956).

YOUNG, F. J., Steam Stripping Carbon Dioxide from Sodium Bicarbonate Solutions (1956). (EES)

M.S. in Engineering

SHELTON, F. J., An Evaluation of Catalysts Containing Iron, Molybdenum, and Vanadium Oxides in the Vapor Phase Oxidation of Crotonaldehyde to Maleic Anhydride (1956).

CIVIL ENGINEERING

Bogan, R. H., "Biochemical Behavior of Synthetic Detergents" **(with C. N. Sawyer, J. R., Simpson),** *Indus. and Engg. Chem.,* **48** (1956).

———, "Biochemical Degradation of Synthetic Detergents: III. Relationships Between Biological Degradation and Froth Persistence" **(with C. N. Sawyer),** *Sew. and Indus. Wastes.,* **28,** 5 (1956).

———, "A New Critical Phase of the Lake Washington Pollution Problem: III. Treatment and Control of Nutritional Elements," *The Trend in Engineering,* Vol. 8, No. 2 (April, 1956).

———, Biochemical Degradation Products—A New Dimension in Stream Pollution," *Proceed.,* 12th Purdue Uni. Indus. Waste Conf., (to appear) Dec., 1957.

Chenoweth, H. H., "Evaluation of Three Types of Fish Rearing Ponds" **(with R. E. Burrows),** Res. Rep. 39, Fish and Wildlife Service, Sup't Documents, U. S. Gov. Printing Office, 1956.

———, "A Model Study of Some Fish Facilities for the Proposed Mayfield Dam: Part II. Upstream Migrant System" **(with E. P. Richey),** *The Trend in Engineering,* Vol. 9, No. 2 (April, 1957).

Clanton, J. R., "An Aid in the Preliminary Design of Prestressed Concrete Beams," *The Trend in Engineering,* Vol. 9, No. 2 (April, 1957).

Colcord, J. E., "The TAF Phototheodolite and Its Use in Glacier Surveys," *Photogram. Engg.,* June, 1957.

Danielson, D. H., "Model Analysis of Pavement Stresses" **(with L. M. LaCross, M. Ekse),** *The Trend in Engineering,* Vol. 8, No. 2 (April, 1956).

Ekse, M., "Incremental Cost Study," *Allocation of Road and Street Costs,* Washington State Council for Highway Research, June, 1956.

———, "Model Analysis of Pavement Stresses" **(with D. H. Danielson, L. M. La Cross),** *The Trend in Engineering,* Vol. 8, No. 2 (April, 1956).

———, "A Laboratory Model Highway Test Track," *Proceed.*, N.W.Conf. on Road Building, Feb. 1957.
———, "Model Analysis of Flexible Pavement and Subgrade Stresses," *Proceed.*, AAPT, Vol. 26, Feb. 1957.
Erlijmann, H., "A Rotation Indicator for Plastic Bending" **(with D. D. Vasarhelyi),** *The Trend in Engineering,* Vol. 8, No. 4 (Oct. 1956).
Farquharson, F. B., "Wind Tunnel Investigation of Conductor Vibration with Use of Rigid Models" **(with R. E. McHugh),** *Pow. Appar. and Sys.* (AIEE), No. 26 (Oct. 1956). (EES Reprint No. 106)
Hartz, B. J., Inelastic Response of Columns to Dynamic Loadings," ASCE, *Proceed., Jour. Engg. Mech. Div.*, Vol. 83, No. EM 2 (April, 1957). (Also Ph. D. Dissertation, same title, Uni. of California, Sept. 1955.)
Hennes, R. G., *Sharing the Cost of Roads and Streets in Washington,* Wash. State Council for Highway Research, June, 1956.
———, *Allocation of Road and Street Costs* (with others), *Ibid.*
———, *On the Incremental Analysis of Highway Cost Responsibility, Ibid.*, Bull. 121.
———, "The Quest for Rational Pavement Design," *Proceed.*, AAPT, Vol. 25, Feb. 1956. (EES Reprint No. 109)
———, "Value of Real Property as a Function of Improved Access" **(with B. O. Wheeler),** Urban Motorways Conf., Brit. Road Fed. (London), Sept. 1956. (EES Reprint No. 112)
———, "Freeways and the Suburbs," *Traffic Quart.*, Eno Foundation, Vol. 10, No. 4 (Oct., 1956). (EES Reprint No. 107)
———, "Flexible Pavement Thickness Design," *Proceed.* AAPT (Asphalt Paving Technology and Construction Seminar), Purdue Uni., Aug. 1956. (Accepted for publication.)
———, "Washington Highway Economic Impact Studies" **(with B. O. Wheeler, W. L. Garrison),** *Proceed.*, Highway Research Board, Vol. 36, 1957.
———, "Allocation of Road and Street Costs" **(with W. W. Mylroie),** *Ibid.*
———, "Responsibility for the Cost of Roads," *Proceed.*, N.W. Conf. on Road Building, 1956.
———, *Washington State Survival Plan* (with others), 2 vols., Uni. of Washington, 1956.
———, "Device for Measuring the Swell Pressure of Soil" **(with B. J. Strom),** *The Trend in Engineering,* Vol. 9, No. 3 (July, 1957).
Knudson, R. O., "Thin-Walled Box Beams Under Pure Bending **(with D. D. Vasarhelyi),** *Public.*, Internat. Assoc. for Bridge and Struct. Engin., Vol. 15 (Nov. 1955). (EES Reprint No. 101)
La Cross, L. M., "Model Analysis of Pavement Stresses" **(with D. H. Danielson, M. Eske),** *The Trend in Engineering,* Vol. 8, No. 2 (April, 1956).
Miller, A. L., "Plaster Cracking as a Measure of Building Motion," *The Trend in Engineering,* Vol. 8, No. 1, (Jan. 1956).
Mylroie, W. W., "Allocation of Road and Street Costs," **(with R. G. Hennes),** *Proceed.*, Highway Research Board, Vol. 36, 1937.
Richey, E. P., "A Model Study of Some Fish Facilities for the Proposed Mayfield Dam: Part I. The Skimmer," *The Trend in Engineering,* Vol. 9, No. 1 (Jan. 1957).
———, *Ibid:* "Part II Upstream Migrant System," **(with H. H. Chenoweth),** *The Trend in Engineering,* Vol. 9, No. 2 (April, 1957)
Rogers, E. H., "A Model Study of Sewage Pollution in Puget Sound" **(with R. J. Tyler, W. S. Tsao),** *The Trend in Engineering,* Vol. 8, No. 1 (Jan. 1956).
Strom, B. J., "Device for Measuring the Swell Pressure of Soil," **(with R. G. Hennes),** *The Trend in Engineering,* Vol. 9, No. 3 (July, 1957).
Sylvester, R. O., "A New Critical Phase of the Lake Washington Pollution Problem: Part I. A Paradox of Water-Pollution Control," *The Trend in Engineering,* Vol. 8, No. 2 (April, 1956).
———, "A Study of the Preoperational Environment in the Vicinity of a New Oil Refinery," *Engg. Bu'l.*, Purdue Uni., Vol. XLI, 2 (June, 1957).
———, "The Value of a Background Study," *Sew. and Indus. Wastes,* **29,** 5 (May, 1957). (EES Reprint No. 118).
———, "Water Quality Studies in the Columbia River Basin," U. S. Fish and Wildlife Service Report, June, 1957.
Tsao, W. S., "A Model Study of Sewage Pollution in Puget Sound," **(with R. G. Tyler, E. H. Rogers)** *The Trend in Engineering,* Vol. 8, No. 1 (Jan. 1956).
Tyler, R. G., "A Model Study of Sewage Pollution in Puget Sound," **(with E. H. Rogers, W. S. Tsao)** *The Trend in Engineering,* Vol. 8, No. 1 (Jan. 1956).
for Bridge and Struct. Engineer., Vol. 15, Nov. 1955.
Vasarhelyi, D D., "Thin Walled Box Beams Under Pure Bending" **(with R. O. Knudson),** *Public.*, Internat. Assoc. for Bridge and Struct. Engineer., Vol. 15, Nov. 1955. (EES Reprint No. 101)
———, "Welded Reinforcement of Openings in Structural Steel Members" **(with R. A. Hechtman),** *Weld. Jour. Res. Suppl.* Vol. XXI, No. 9 (Sept. 1956). (EES Reprint No. 104)
———, "Bolted Joints Research," *The Trend in Engineering,* Vol. 8, No. 3 (July, 1956).
———, "A Rotation Indicator for Plastic Bending Test" **(with H. Erlijmann),** *The Trend in Engineering,* Vol. 8, No. 4 (Oct. 1956).

M.S. in Civil Engineering

ABADI, F. M., A Preliminary Study of Warping of Unsymmetrically Reinforced Concrete Beams Due to Shrinkage (1957). (EES)
BUNTIN, W. D., Cylindrical Shell Theory to Include the Application of a Line Load (1957).
CHAO, R. C-C., Effects of Temperature, Humidity, Duration of Air Circulation, and Void Ratio upon Moisture Condensation in Subgrade Soil (1957). (EES)
CHAUNER, R. W., The Effect of Vibration on the Slip of Bolted Joints (1957).
CHENOWETH, H. H.: "Establishment of Flow in a Closed Rectangular Conduit (1957).
DANIELSON, D. H., Model Analysis for Highway Pavements (1956). (EES)
ERLIJMANN, HORACIO, Plastic Bending of Steel Beams at Low Temperature (1956). (EES)
FINN, W. D., Swelling of Soils (1957). (EES)
GOBLE, G. G., Investigations of Doubly Reinforced Concrete Beams to Verify the Ultimate Stress Theory (1957).
HAWKINS, S. E., Slope Deformation and Safety as Related to Railway Landslide Problems (1956). (EES)
LA CROSS, L. M., Instrumentation and Verification of a Model Highway Test Track (1956). (EES)
LU, Z-A., Slip of High Tensile Bolted Joints Tightened by the One-Turn-of-the-Nut Method (1957). (EES)
MACARTNEY, T. W., A Study of Snow and Ice Controls: Main Costs on the Highways of the State of Washington (1957).
MADISON, R. B., The Effect of Misaligned Holes, Punched Holes, Painted Faying Surfaces, and Low Temperature on the Behavior of High-Strength Bolted Joints (1956). (EES)

MARTIN, R. A., Preliminary Investigation of the Hydroelectric Resources of the Duckabush and Dosewallips Rivers. (1957)

MCCOY, E. L., The Effect of Drainage on Landslide Control (1956). (EES)

MIAO, L.-S., An Investigation of Flow Through an Open Channel with Screen Bed (1957). (EES)

MYHRE, S. H., Effect of Production Processes on Fatigue Strength of Aluminum Alloy 7075-T6. (1957)

OKEY, R. W., The Study of Present and Future Pollutional Effects in the Green-Duwamish River (1957).

ROGERS, E. H., A Pollution Study of Puget Sound Using a Hydraulic Model (1956).

SANGESAND, D. A., Exploratory Study of Warping of Reinforced Concrete (1956).

STABLOOM, R. W., Water Quality Studies in the Wenatchee River Basin (1956).

STERN, P. H., Behavior of a Thin Walled Box Beam Subject to Combined Moment and Shear (1956).

STIMSON, M. S., An Economy Study of a Proposed Bothell Way Bypass Through the Lake City Shopping District in Seattle (1956).

STROM, B., A Device for Measuring the Swell Pressure of Soils (1957). (EES)

UNDERWOOD, J. L., Prediction of Short Term Runoff Using Multiple Linear Regression (1957).

VASISHTH, V. C., A Study of Efficiency and of Friction in Structural Steel Joints Fastened by High Tensile Bolts (1957).

WHITE, G. B., A Study of the Biochemical Oxidation of Alkyl Anyl Sulfonates (1957). (EES)

ELECTRICAL ENGINEERING

Arya, M., "Polarization in the A-C Electromagnetic Flowmeter" **(with J. H. Fisher),** *The Trend in Engineering,* Vol. 8, No. 3 (July, 1956).

Bergseth, F. R. "An Electronic Distance Relay Using a Phase Discrimination Principle," *Trans. A.I.E.E.,* Vol. 73 (1914). (EES Reprint No. 89)

———, "Effect of Shock and Vibration on Relays," discussion, *Trans. A.I.E.E.,* Vol. 74 (1955).

———, "A Transistorized Distance Relay," A.I.E.E. Conference Paper No. 56-816, June, 1956.

Fisher J. H., "Polarization in the A-C Electromagnetic Flowmeter" **(with M. Arya),** *The Trend in Engineering,* Vol. 8, No. 3 (July, 1956).

Harrison, A. E., "Glacial Activity in the Western United States," *Jour. Glac.* Vol. 2, No. 19 (Mar. 1956).

———, "Fluctuations of the Nisqually Glacier, Mt. Rainier, Washington, since 1750," *Ibid.*

———, "Multiple Glaciation since the Ice Age," *Science,* 124, 3213 (July 27, 1956).

———, "Photogrammetry of Glaciers," *The Trend in Engineering,* Vol. 9, No. 3 (July, 1957).

Held, G., "Broad Band Excitation of Multimodes and the Associated Radiation Patterns" **(with A. W. Guy, R. F. Tighe),** Tech. Rep. No. 21, Dep't Elect. Engg., Univ. of Wash. (Prepared for the Physical Research Staff,Boeing Airplane Co.) Feb. 1957.

———, "Dielectric Loading of Waveguides" **(with W. V. Kiskaddon),** Tech. Rep. No. 22, Dept. Elect. Engg., Univ. of Wash. (Prepared for the Physical Research Staff, Boeing Airplane Co.) Mar., 1957).

———, "Dielectric Loading of Waveguides" **(with W. V. Kiskaddon),** *The Trend in Engineering,* Vol. 9, No. 3 (July, 1957).

Johnson, D. L., "Digital Computer Solution to Determine Economical Use of Hydro Storage," *Power Appar. and Sys.* (AIEE), Dec., 1956. (EES Reprint No. 110)

———, "Application of Digital Computers in Power-System Hydro-Storage Problems," *The Trend in Engineering,* Vol. 9, No. 2 (April, 1957).

———, "Solution of Power-System Stability Problems by means of Digital Computers" **(with J. B. Ward),** AIEE Paper No. 56-923, 1956. (EES Reprint No. 114)

Kiskaddon, W. V., "Dielectric Loading of Waveguides" **(with G. Held),** Tech. Rep. No. 22, Dept. Elect. Engg., Univ. of Wash. (Prepared for the Antenna and Electronics Equip. Unit, Boeing Airplane Co.) Mar., 1957.

———, "Dielectric Loading of Waveguides" **(with G. Held),** *The Trend in Engineering,* Vol. 9, No. 2 (July, 1957).

Shafer, D. E., "An Analog Computer Method for Solving Sets of Non-Linear Algebraic Equations," *The Trend in Engineering,* Vol. 8, No. 1 (Jan., 1956).

Smith, G. S., "Intermittent Ground Grids for Heat Pumps," *Trans.,* A.S.H.A.C.E. Vol. 62 (1956). (EES Reprint No. 105)

Stathacopoulos, A. D., "Noun Phrase Analysis Using the IBM 650 Computer," *The Trend in Engineering,* Vol. 9, No. 2 (April, 1957).

Wall, R. E., "Some of the Engineering Aspects of the Machine Translation of Language," *Commun. and Electron.* (AIEE), Nov., 1956. (EES Reprint No. 108)

———, "Engineering Progress in Machine Translation," *The Trend in Engineering,* Vol. 8, No. 3 (July, 1956).

M.S. in Electrical Engineering

CHADWICK, D. G., A Point-Contact Transistor Multiplier (1957).

CHOU, T-L., Transistor Class C Oscillator Design (1956).

COLVIN, R. S., An Information Storage System Using a Coded Conducting Medium and Electrostatic Read-Out (1956).

DASU, S. B. V., The Investigation of Interference from Flexible Single and Double Sheath Cables (1956). (EES)

DEMUTH, H. P., Experiments to Determine Errors in Distances Measured by Shoran Equipment as Applied to Hydrographic Surveys (1956).

GUY, A. W., Broadband Excitation of Multimode Waves (1957).

HAMMERSAND, F. G., The Design and Performance of an Experimental High-Power Klystron Electron Gun (1956).

JOHNSON, L. W., Use of an Analog Computer in the Solution of an Automatic Flight Control Problem (1956).

KELLY, J. D., A Fixed Tuned Broadband Barreter Mount Using a Resonant Window and an Inductive Post (1956).

KIEBURTZ, R. R., Rise Time in a Transistor Pulse Circuit (1957).

KISKADDON, W. V., Dielectric Loading of Waveguides (1957).

MCNELIS, D. D., Variation of Polarization with Frequency in the A-C Electromagnetic Flowmeter (1956).

MOORE, D. W., The Design of a Practical Russian-English Mechanical Translator (1957). (EES)

OH, L. L., Design and Experimental Test of Coupled Helices (1957). (EES)

OTOSHI, T. Y., Investigation of the Cut-off Region for a Microwave Metal-Strip Artificial Dielectric (1957.)

TSAO, C-M., A Study of the Voltage Conditions of a Potential Transformer Connected from One Line-to-Ground on an Isolated Delta System (1956).

SCHOMBERG, R. A., The Utilization of VHF Propagational Flutter for Short-Range Aircraft Detection (1956).

TYRAS, G., Radiation from a Rectangular Waveguide Filled with Ferrite (1957).

VERMILION, E. E., A Commutator Inverter (1956).

WAGGONER, R. S., Design Considerations for Mechanical Language Translators (1956). (EES)

WILLARD, H. R., A Low-Impedance Power Demodular System (1957).

YEE, J. S-J., Second Order Beams of Two-Dimensional Slot Arrays (1956). (EES)

M.S. in Engineering

BUNTIN, W. D., Cylindrical Shell Theory to Include the Application of a Line Load (1957).

CARLYLE, J. W., Singular Electric Transients (1957).

SHAFER, D. E., An Analog Computer Method for Solving Sets of Non-Linear Algebraic Equations (1956).

GENERAL ENGINEERING

Bartlett, F. G., "Some Aspects of Mobile-Cargo Ships in Great Lakes Trade, *Great Lakes Section, Soc. Naval Arch. and Marine Engin.,* June 14, 1957.

Hoag, A. L., *Engineering and Technical Handbook* **(with D. C. McNeese),** New York, Prentice-Hall, Inc., Jan., 1957.

Jacobsen, P. A., "A Film Age for Education," *Jour. Soc. Motion Pic. and Telev. Engrs.,* Vol. 5, No. 3 (Mar., 1956).

McNeese, D. C., *Engineering and Technical Handbook* **(with A. L. Hoag),** New York, Prentice-Hall, Inc., Jan., 1957.

Seabloom, R. W., "Water Quality Studies in the Wenatchee River Basin," U. S. Fish and Wildlife Service Report, June, 1957.

Stern, P. H., "Pressure Line for a Two-Hinged Arch Rib Subject to Vertical Loads," *The Trend in Engineering,* Vol. 8, No. 2 (April, 1956).

HUMANISTIC-SOCIAL STUDIES

Souther, J. W., *Technical Report Writing,* New York, John Wiley & Sons. (In press, to be issued Jan., 1958.)

Trimble, L. P., "Sound Structure and Historical Phonology," *Word,* to be published in 1957.

MECHANICAL ENGINEERING

Balise, P. L., "Instrumentation Education at the Section **(with H. E. Myers),** *Proceed., Inst. Soc. of Am.,* Vol. 10 (1955).

———, "Getting the YET Message Across," *Jour. Engg. Ed.,* Vol. 46, No. 1 (Sept., 1955).

———, "Feedback—Key to Automation," *Puget Sound Engg.,* Vol. X, No. 11 (Nov., 1955).

Crain, R. W., Sr., "A Solar Radiation Apparatus," *Trans.,* World Symposium on Applied Solar Energy, Spring, 1957.

———, "Solar Energy Collection in the Pacific Northwest," *Jour. Solar Energy Sci. and Engg.,* Sept., 1957.

Day, E. E., "Strain Energy Release Rate Determination for Some Perforated Structural Members," *Weld. Jour. Res. Supp.,* Jan., 1956.

———, "An Efficiency Study of Double Enveloping Worm Gears" **(with B-L. Ho),** *The Trend in Engineering,* Vol. 8, No. 3 (July, 1956).

———, "Performance of Foil Type High-Temperature Strain Gages up to 700° F," *Proceed.,* Soc. for Exper. Stress Analysis. To appear in Vol. XV, No. 2 (1957).

Firey, J. C., "A Detonation Wave Theory of Gasoline Engine Knock," *Proceed.,* 6th International Symposium on Combustion, June, 1957.

———, "Pressure Drop and Critical Flow of Steam-Water Mixture" **(with R. W. Moulton)** G. E. Co. Seminar on Particulate Suspensions (Jan., 1957).

Hendrickson, H. M., "Air Conditioning Calculations," Chapter 14, *ASRE Data Book: Design,* 9th ed. (1955-56).

———, "Fishing Boats," Chapter 32, *ASRE Data Book: Applications,* 6th ed. (1956-57).

Ho, B-L., "An Efficiency Study of Double Enveloping Worm Gears" **(with E. E. Day),** *The Trend in Engineering,* Vol. 8, No. 3 (July, 1956).

Mills, B. D., Jr., "Relativity and the Engineer," *Washington Engineer,* Vol. IX, No. 5 (April, 1957).

———, "Some Aspects of Einstein's Relativity in Engineering Education," *Jour. Engg. Ed.,* Vol. 47, No. 8 (April, 1957).

———, "The Centrifugal Force Aspect of High-Speed Belting," *Mach. Design and Mfg Bull.* (ASEE), Vol. XXII, No. 6 (April-May, 1956).

Morrison, J. B., "O-Rings and Interference Seals for Static Applications," *Mach. Design,* Vol. 29, No. 3 (Feb. 7, 1957). (EES Reprint No. 113)

Schaller, G. S., "Welding Progression," *Puget Sound Engg. Bulletin,* Vol. XXII, No. 5 (May, 1957).

Snyder, W. A., "Casting Design—a Teaching Method" **(with L. B. Zylstra)** *Foundry,* Feb., 1957. (EES Reprint No. 115)

Winslow, A. M., "Stress Solutions for Rectangular Plates by Conformal Transformation," *Quart. Jour. Mech. and App. Math.,* Vol. X, Part 2 (May, 1957). (EES Reprint No. 117)

Zylstra, L. B., "Casting Design—a Teaching Method" **(with W. A. Snyder),** *Foundry,* Feb., 1957. (EES Reprint No. 115)

———, "Voice from Across the Tracks," *Jour. Engg. Ed.,* Mar., 1957. (EES Reprint No. 116)

M.S. in Mechanical Engineering

BROWN, F. J., Design and Instrumentation of a Solar Heat Collector (1956).

BROWNFIELD, C. P., Cold Deformation Studies of Ductile Iron (1956). (EES)

BURNS, F. W., Aircraft Evaporative Hydraulic Air Cooler (1956).

COOLEY, W. H., Study of the Stability of Thin-Walled Tubing (1957).

DOTSON, B. F., An Investigation of the Stress Relaxation of Thioplast Rubber Under Triaxial Stress (1956). (EES)

FARMAN-FARMIAN, H. A-R., Desalting of Sea Water by Freezing Processes (1956). (EES)

Ho, B-L., Efficiency of Worm Gears (1957). (EES)

HOLEN, J., New Techniques in Photoelasticity (1957).

KIRSCHNER, D. J., Analytical and Experimental Determination of Thermal Lag of Airplane Tires (1957).

KIRBY, R. L., A Study of Drives Considered in the Design of a Viscose Rayon Continuous Spinning and Finishing Machine (1957).

KONECNY, A. R., An Applied Appraisal of Cutting Elements for Machine Tools (1956).

LAPINS, U. E., A Supersonic Flow Channel for Study of Base Pressure Problems (1956). (EES)

MILLS, W. B., Instability Study on Liquid Flow Through Small Orifices into Gaseous Regions (1956).

REESE, B. O., Evaluation of a Solar Energy Collector (1956).

THORSEN, T., Purification of Saline Water by Freezing (1956). (EES)

TJONNELAND, E., The Development and Study of a Liquid Level Analog of Automatic Control Principles (1956). (EES)

MINERAL ENGINEERING

Brien, F. B., "The Role of the Fifty-Ton Pilot Plant at Flin Flow," *Canad. Min. & Metall. Bull.,* **49,** 536 (Dec., 1956). (Also, *Trans.,* Vol. LIX, 1956.)

——— "Recent Advances in Insol Control During Flotation," *Ibid.*

———, "Uranium Leaching at Rayrock Mines," Brit. Commonwealth Min. Congress, Milling Volume, 1957.

Daniels, J., "Analysis of Washing on Coals," Supplement to Tech. Papers 491, 618, U.S.B.M. Bull. 572 (in press).

Kelly, H. J., "The Use of Bentonite as a Hydro-Seal" **(with K. G. Strandberg, H. M. Harris)**, *The Trend in Engineering*, Vol. 8, No. 4 (Oct., 1956).

Mueller, E. E., "Industrial Silica in the Pacific Northwest," *The Trend in Engineering*, Vol. 9, No. 1 (Jan., 1957).

Mueller, J. I., "Heavy Element Impurity in a Beryllium Shim Safety Rod" **(with H. G. Simens, R. E. Mayes)**, Pratt-Whitney Aircraft TIM No. 157, Sept., 1956, *Nuclear Sci.*, Abst. No. 1328, Vol. II, (Jan. 31, 1957).

———, "Procedure for Fluorescent X-Ray Spectrographic Analysis on Radioactive Samples" **(with R. E. Mayes, H. G. Simens)**, Pratt-Whitney TIM No. 507 Jan. 2, 1957.

Polonis, D. H., "Phase Transformations in Titanium-Rich Alloys of Nickel and Titanium," *Trans.*, AIME, **206**, 531 (1956), *Jour. of Metals*, May 1956.

——— "Sub-Structures in Retained Beta-Phase of Titanium-Nickel Alloys," *Trans.*, AIME, **206**, 514 (1956), *Jour. of Metals*, May 1956.

———, "Orientation Relationships Between Alpha-Prime and Retained Beta Phases in a Titanium-Nickel Alloy," *Trans.*, AIME, **206**, 892 (1956).

———, "Zone Melting: A Physical Method for Controlling Impurities of Metals," *The Trend in Engineering*, Vol. 9, No. 2 (April, 1957).

———, "Titanium" **(with A. D. McQuillan, M. K. McQuillan)**, *Jour. Inst. Metals* (Great Britain), **85**, No. 6 (Feb., 1957).

———, Reply to discussion of "Phase Transformations in Titanium-Rich Alloys of Nickel and Titanium," *Trans.*, AIME, **209**, 1957, *Jour. of Metals Supp.*, Feb., 1957.

Roberts, E. C., "All-Glass Multiple-Test Apparatus for Corrosion Testing of Stainless Steel," ASTM Bull. No. 214, May, 1956.

———, "Vacuum Metallurgy" *The Trend in Engineering*, Vol. 8, No. 4 (Oct., 1956).

———, "Whisker-on-Whisker Growth" (letter to the Editor), *Acta Metal.*, June, 1957.

——— "The Effect of Manganese on the Curie Point of Cementite," *Trans. Am. Soc. for Metals*, Vol. 49 (1957).

M.S. in Ceramic Engineering

CORWIN, P. R., Electrical Porcelain: Utilization of Northwest Materials (1956).

MCCORMICK, S. W., A Study of the Attack of Molten Iron on Fire Clay Refractories (1956).

SIDDIQUI, M. I. A., The Formation of Mullite (1956). (EES)

SIMPSON, F. H., Application of Fluid Mechanics to the Stiff-Mud Extrusion Process (1956).

WANG, C-H., Effect of Heat Treatment on Modulus of Elasticity of Clay Bodies (1956).

M.S. in Metallurgy

ALGER, J. V., A Study of the Corrosion Behavior of Plastically Deformed Type 304L Stainless Steel (1956).

HOLT, R. E., Effects of Thermal Expansion on a Uniaxially Confined Cylinder of 5052-34 Aluminum Alloy (1957).

MONTGOMERY, D. M., A Study of the Beta Phase Decomposition in a Eutectoid Copper-Beryllium Alloy (1957).

NELSON, R. D., Transformation Studies of the Delta and Gamma Eutectoid Alloys of the Copper-Tin System (1957).

M.S. in Mining Engineering

RICE, G. R., Dewatering a Fine Coal Slurry by Means of a Screen and Cyclone (1956).

WEST, J. M., Investigation of Methods for Measuring Viscosity of Dense-Mediums Used in Coal Cleaning (1956).

DIELECTRIC LOADING OF WAVEGUIDES

(Continued from page 19)

Conclusions

Propagation of a TE_{10} mode through a loaded guide was successfully predicted by Eq. 12. Both the phase shift and passbands were accurately determined.

The dielectric loaded guide is similar to a disk-loaded guide since they both have alternating pass- and stop-bands. By changing the dimensions of the blocks and the materials used for loading, different pass- and stop-bands are possible. Thus, one possible use of this dielectric guide is a microwave bandpass or band-elimination filter.

The problem of designing a workable dielectric loaded guide filter has received but little attention. Such a design procedure would include determining a loading by choosing l_1 and l_2 and ϵ_2 that would yield desired pass- and attenuation-bands. The total length of loaded guide could be chosen to yield a desired phase shift.

In order to function well as a filter, the loaded guide would have to be reasonably well matched to the lines connecting both ends of the filter guide over the passbands. Examination of Eq. 17, shows that the reflection coefficient is zero if $\sin \theta_2$ is zero. This would be achieved if $\theta_2 = n\lambda$. Thus, if θ_2 is kept near $n\lambda$ throughout a passband, the problem of matching is minimized. If this is not possible, a matching device similar to the two movable quarter-wave dielectric plates described in the introduction might be used. A loaded guide with a number of movable loading plates with free space between might possibly be a means of attaining a better match and some control over the cutoff points. A number of loaded guides, each with different values of l_1 and l_2, connected together, might yield sharper cutoff characteristics. Guides with adjustable loading could be placed between these differently loaded guides.

The foregoing suggestions have been put forth as possible starting points on this problem.

REFERENCES

1. RAMO, S., and WHINNERY, J. R., *Fields and Waves in Modern Radio*, 2nd ed., New York, John Wiley and Sons, 1953.
2. MONTGOMERY, C. G., DICKE, R. H., and PURCELL, E. M., *Principles of Microwave Circuits*, New York, McGraw-Hill Book Co., Inc., 1948.
3. KISKADDON, W. V., "Dielectric Loading of Waveguides," unpublished M.S. thesis, University of Washington, 1957.
4. MONTGOMERY, C. G., *Techniques of Microwave Measurements*, New York, McGraw-Hill Book Co., Inc., 1947.

PUBLICATIONS

of the

ENGINEERING EXPERIMENT STATION

UNIVERSITY OF WASHINGTON

Requests for copies of publications should be addressed to the Director, Engineering Experiment Station, University of Washington, Seattle 5.

BULLETINS

48. The Influence of Pipe Thickness on Re-Entrant Intake Losses. Charles William Harris, 35 pp. 1928.
54. Elimination of Hydraulic Eddy Current Loss at Intake. Charles W. Harris. 30 pp. 1930.
55. Vacuum-Tube Control for Electric Wind-Tunnel Balances. Fred S. Eastman. 20 pp. 1931.
56. Constant Flow Characteristic of the Plane Orifice in Proximity to Side Walls. Charles William Haris. 18 pp. 1931.
58. Preliminary Tests of Thirteen Washington Coals in a Powdered Coal Boiler Plant at the University of Washington. George Samuel Wilson, Harry Fagan Yancey, and Joseph Daniels. 27 pp. 1931.
60. An Electromagnetic Balance for Force Measurement of Current Control. Fred Scoville Eastman. 29 pp. 1932.
61. Hydraulic Flow Characteristics of a Square-Edged Intake. Charles William Harris. 21 pp. 1932.
67. The Doherty Washer Cooler. Sybren Ruurd Tymstra. 61 pp. 1932.
69. Studies in Hydrogenation of Certain American Coals. Warren L. Beuschlein, Bert E. Christensen, and Calvert C. Wright. 24 pp. 1933.
72. The Derivation of the Mean Temperature Difference Between a Saturated Gas and a Cooling Liquid, and also the Derivation of the Mean Velocity of Such Gas. Sybren Ruurd Tymstra. 19 pp. 1933.
74. The Deformation of Hard Grade Reinforcing Steel During and After Construction in a Reinforced Concrete Building. Sergius Ivan Sergev. 33 pp. 1933.
75. The Water Tube Gas Condenser. Sybren Ruurd Tymstra. 24 pp. 1934.
77. A Study of Fundamental Relations of the Mathematical Theory of Elasticity. Arthur Melvin Winslow. 25 pp. 1934.
81. Influence of Two Secondary Factors in Weir Measurement. Charles William Harris. 16 pp. 1935.
84. Equations for Calculating Three Phase Symmetrical Components. Gordon Russell Shuck. 32 pp. 1935.
85. Discharge of Three Commercial Cippoletti Weirs. Robert Bowman Van Horn. 32 pp. 1935.
87. Open Water Testing of Ship Models. Thomas McKie Rowlands. 20 pp. 1935.
88. The Properties of Quartz Sands Washed from Kaolins of the Pacific Northwest. Hewitt Wilson and Frank Joseph Zvanut. 42 pp. 1936.
90. Hydroelectric Power in Washington. Part IV, Regional Electric-Power Transmission. The Grid System. Carl Edward Magnusson. 51 pp. 1936.
91. The Analysis and Control of Landslides. Robert Graham Hennes. 57 pp. 1936.
92. Moment Equations. A Method of Analysis for Continuous Beams and Rigid Frames. Alfred Jensen. 88 pp. 1937.
93. Electric Power Markets in Washington. Part I, Electric Heating of Residences. Carl Edward Magnusson. 40 pp. 1937.
94. Evaporation and Surface Cooling. George Samuel Wilson and William Lyle Dudley. 18 pp. 1937.
96. Hydroelectric Power in Washington. Part VI, International Boundary Waters. Carl Edward Magnusson. 17 pp. 1937.
98. Geology and Its Relation to the Occurrence of Oil in Washington. Charles Edwin Weaver. 16 pp. 1938.
100. Modernization of a Transit System. Factors that Determine the Choice of a Vehicle. George Lisle Hoard. 36 pp. 1940.
101. Buckling Criteria and Design of Two-Story Columns. Sergius I. Sergev. 48 pp. 1940.
102. An Investigation of Prestressed Stays. T. M. Rowlands and F. C. Smith. 36 pp. 1941.
103. Bismuth Bridge Magnetic Flux Meter. George Sherman Smith. 48 pp. 1940.
104. The Telechronometer, Telephone Service Measurement in Units of Time. Lyall Baker Cochran. 68 pp. 1941.
106. The Shearing Strength of Cement Mortar. Frederick C. Smith and Robert Q. Brown. 32 pp. 1941.
109. The Number of Teeth in Contact as a Vibration Factor in Involute Cut Gears. Sybren Ruurd Tymstra. 16 pp. 1942.
110. Solutions for Torsional Vibration Frequencies by Energy Method. Arthur Melvin Winslow. 22 pp. 1943.
111. Stabilized Earth Blocks for Protective Construction. Robert G. Hennes. 24 pp. 1943.
112. Hydraulic Models. Charles W. Harris. 17 pp. 1944.
114. The Effect of Shearing Forces on the Deflection and Strength of Beams. Sergius I. Sergev. 20 pp. 1947.
116. Aerodynamic Stability of Suspension Bridges with Special Reference to the Tacoma Narrows Bridge. Part I, Investigations Prior to October, 1941. F. B. Farquharson. 103 pp. 1949.
116. Aerodynamic Stability of Suspension Bridges with Special Reference to the Tacoma Narrows Bridge. Part II, Mathematical Analyses. F. C. Smith and G. S. Vincent. 63 pp. 1950.
116. Aerodynamic Stability of Suspension Bridges with Special Reference to the Tacoma Narrows Bridge. Part III, The Investigation of Models of the Original Tacoma Narrows Bridge Under the Action of Wind. F. B. Farquharson. 125 pp. 1952.
116. Aerodynamic Stability of Suspension Bridges with Special Reference to the Tacoma Narrows Bridge. Part IV, The Investigation of Models of the New Tacoma Narrows Bridge Under the Action of Wind. F. B. Farquharson. 104 pp. 1954.
116. Aerodynamic Stability of Suspension Bridges with Special Reference to the Tacoma Narrows Bridge. Part V, Extended Studies: Logarithmic Decrement, Field Damping, Prototype Predictions, Four Other Bridges. G. S. Vincent. 104 pp. 1954.
118. Investigations in Aeronautics from the Department of Aeronautical Engineering. Edited by R. M. Rosenberg. 120 pp. 1951.
119. The Extremum Principles of the Mathematical Theory of Elasticity and Their Use in Stress Analysis. (The Walker-Ames lectures of the Spring Quarter, 1950.) W. Prager (Brown University). 30 pp. 1951.

REPORTS

2. Iron and Steel Manufacture in Washington, Oregon. California, and Utah. Joseph Daniels. 69 pp. 1929.
3. Coal in Washington. Joseph Daniels. 17 pp. 1934.
4. Water Resources of Washington. Richard Gaines Tyler. 61 pp. 1938.

TECHNICAL NOTES

3. The Theory of Fractional Parts Developed for Structural Beam-Column Members Preceded by an Elementary Discussion of Simple Beam and Column Design. Sybren Ruurd Tymstra. 32 pp. 1943.
4. Gaging Chart for Horizontal Cylindrical Tanks with Flat Heads or with Convex Heads. Sybren Ruurd Tymstra. 4 pp. 1944.
5. Gaging Chart for Cylindrical Tanks with Different Types of Heads. Sybren Ruurd Tymstra. 7 pp. 1945.
6. The Heat Pump for Residential Heating. G. S. Smith, H. Christensen, and A. Presson. 23 pp. 1948.